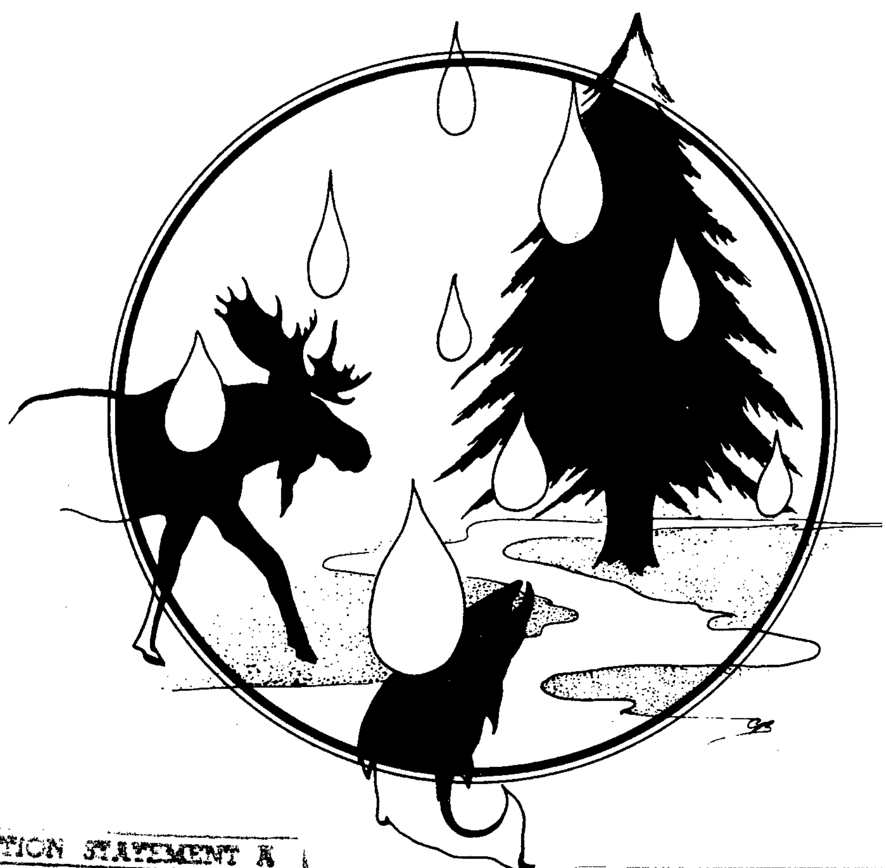
Biological Report 80(40.28)
August 1989

Air Pollution and Acid Rain
Report No. 28

Acid Rain Publications by the U.S. Fish and Wildlife Service, 1979–1989



Fish and Wildlife Service
U.S. Department of the Interior

Biological Report

This publication series of the Fish and Wildlife Service comprises reports on the results of research, developments in technology, and ecological surveys and inventories of effects of land-use changes on fishery and wildlife resources. They may include proceedings of workshops, technical conferences, or symposia; and interpretive bibliographies.

Copies of this publication may be obtained from the Publications Unit, U.S. Fish and Wildlife Service, 18th and C Streets, NW., Room 130, Arlington Square Building,Washington, DC 20240, or may be purchased from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

ISSN 0895-1926

This publication may be cited as follows:

Villella, R. F. 1989. Acid rain publications by the U.S. Fish and Wildlife Service, 1979–1989. U.S. Fish Wildl. Serv., *Biol. Rep.* 80(40.28). 31 pp.

Biological Report 80(40.28)
August 1989

Air Pollution and Acid Rain
Report No. 28

Acid Rain Publications by the U.S. Fish and Wildlife Service, 1979–1989

by

Rita F. Villella

U.S. Fish and Wildlife Service
Acid Precipitation Section
National Fishery Research Center—Leetown
Box 700
Kearneysville, West Virginia 25430

U.S. Department of the Interior
Fish and Wildlife Service
Washington, DC 20240

Preface

Pollution of aquatic and terrestrial ecosystems has been a concern to society since the burning of fossil fuels began in the industrial revolution. In the past decade or so, this concern has been heightened by evidence that chemical transformation in the atmosphere of combustion by-products and subsequent long-range transport can cause environmental damage in remote areas. The extent of this damage and the rates of ecological recovery were largely unknown. "Acid rain" became the environmental issue of the 1980's. To address the increasing concerns of the public, in 1980 the Federal government initiated a 10-year interagency research program to develop information that could be used by the President and the Congress in making decisions for emission controls.

The U.S. Fish and Wildlife Service has been an active participant in acid precipitation research. The Service provided support to a number of scientific conferences and forums, including the Action Seminar on Acid Precipitation held in Toronto, Canada, in 1979, an international symposium on Acidic Precipitation and Fishery Impacts in Northeastern North America in 1981, and a symposium on Acidic Precipitation and Atmospheric Deposition: A Western Perspective in 1982. These meetings as well as the growing involvement with the government's National Acid Precipitation Assessment Program placed the Service in the lead in research on the biological effects of acidic deposition. Research projects have encompassed water chemistry, aquatic invertebrates, amphibians, fish, and waterfowl. Water quality surveys have been conducted to help determine the extent of acid precipitation effects in the Northeast, Middle Atlantic, and Rocky Mountain regions. In addition to lake and stream studies, research in wetlands and some terrestrial habitats has also been conducted. Specific projects have addressed important sport species such as brook trout (*Salvelinus fontinalis*), Atlantic salmon (*Salmo salar*), and striped bass (*Morone saxatilis*). Trace metal accumulation in fish has been investigated and a symposium sponsored on related work. U.S. Fish and Wildlife Service scientists serve as advisors and participants in research being conducted by industry, nonprofit groups, State and other Federal agencies. Researchers have worked closely with colleagues in Canada, England, Norway, Scotland, the Soviet Union, and Sweden to gain additional understanding of the problem.

In 1982, the Service implemented a mitigation research program to provide resource managers with information to help them protect sensitive ecosystems, and rehabilitation methods for resources already affected by acidification. An international workshop was convened to outline the research needs. Several conferences were organized to develop appropriate field and laboratory procedures. Scientists with the mitigation research program are evaluating the ecological effects of liming (addition of base material) surface waters and surrounding watersheds to provide buffering against acidic inputs. Through long-term cooperative projects with States and other organizations, investigators are studying possible abatement methods for regions most affected by acidic deposition.

To date, more than 200 reports that describe these studies have been published. These products include conference proceedings, journal articles, and in-house scientific publications. An educational poster describing the effects of acid rain on aquatic ecosystems was developed and distributed to individuals, conservation and State organizations, and the public education system.

This annotated bibliography lists current publications by Service authors, cooperators, or contractors on acid rain and related air quality. Entries are arranged alphabetically by author surname.

For further information about the research program, contact the U.S. Fish and Wildlife Service, Acid Precipitation Section, National Fishery Research Center—Leetown, Box 700, Kearneysville, WV 25430.

R. Kent Schreiber
Chief, Acid Precipitation Section

Annotated Bibliography

1. ADLER, D. 1982. Air pollution and acid rain, report supplement: the effects of air pollution and acid rain on fish, wildlife, and their habitats. Bibliography. U.S. Fish Wildl. Serv., FWS/OBS-80/40.3–40.11.

   This bibliography contains more than 1,500 references for the nine-volume set (FWS/OBS-80/40.3–40.11) entitled "The effects of air pollution and acid rain on fish, wildlife, and their habitats: introduction, lakes, rivers and streams, forests, grasslands, arctic tundra and alpine meadows, deserts and steppes, urban ecosystems, critical habitats of threatened and endangered species."

2. AKIELASZEK, J., AND T. HAINES. 1981. Mercury in the muscle tissue of fish from three northern Maine lakes. Bull. Environ. Contam. Toxicol. 27:201–208.

   This study reports the levels of mercury in the muscle tissue of brook trout (*Salvelinus fontinalis*) and lake trout (*S. namaycush*) from three northern Maine lakes. The oligotrophic nature of northern Maine lakes enhances accumulation of mercury by fish. Acid precipitation would further enhance mercury uptake.

3. ALBERS, P. H., AND R. M. PROUTY. 1987. Survival of spotted salamander eggs in temporary woodland ponds of coastal Maryland. Environ. Pollut. 46(1):45–61.

   Temporary ponds on the Atlantic Coastal Plain in Maryland were characterized according to water chemistry, rain input, phytoplankton, zooplankton, and use by spotted salamander (*Ambystoma maculatum*). Number of egg masses per unit of pond surface and survival of embryos were not significantly correlated with pond pH. Survival of egg masses transferred among eight ponds was significantly reduced only at pH 3.66. Embryonic survival was negatively correlated with aluminum concentration in pond water.

4. ANDREWS, A. K., G. T. AUBLE, R. A. ELLISON, D. B. HAMILTON, J. E. ROELLE, D. R. MARMOREK, O. L. LOUCKS, AND W. J. MITSCH. Pages 393–400 *in* R. W. Bosserman and J. M. Klopatek, eds. International symposium on energy and ecological modelling, Louisville, Ky., 20 April 1981.

   A structured workshop modeling process, Adaptive Environmental Assessment, is being used to facilitate interdisciplinary and interagency interaction in synthesizing existing knowledge and identifying research needs on the mechanisms by which acid precipitation effects freshwater aquatic resources. The focus of this effort is on construction and iterative refinement of an ecosystem simulation model. The current model is described and evaluated in terms of performance, limitations, utility for identifying research needs, and potential for further refinement and application.

5. ARNOLD, D. E. 1980. Probable effects of acid precipitation on Pennsylvania waters. Pages 1–17 *in* M. Kostic, ed. Proceedings of the national symposium on acid rain. Pittsburgh Chamber of Commerce, Pittsburgh, Pa.

   Pennsylvania produces large amounts of acid rain precursors and receives strong acid rain statewide. Examination of historical water quality data indicates that a large number of Pennsylvania waters are being acidified or are losing acid neutralizing capacity. In many of these cases the number of fish species present, which is a more robust indicator of change, is decreasing.

6. ARNOLD, D. E. 1982. Acidity in rain and snow poses freshwater threat. Sci. Agric. 29(2):2–3.

   Effects of acid rain on the freshwater resources of Pennsylvania are described, and research in progress, including mitigation studies, is summarized.

7. ARNOLD, D. E. 1982. An experimental limestone flow-through device for maintenance of pH in poorly-buffered streams. Pages 347–348 *in* R. E. Johnson, ed. Acid rain/fisheries. American Fisheries Society, Bethesda, Md. 357 pp. (Abstract)

   A prototype mitigation device emphasizing low cost and low maintenance was constructed from wire gabions filled with limestone chunks. Water chemistry monitoring was continued for nearly a year after installation, but after the first 2 weeks effects were not significant. However, a series of such devices using high calcium, uniform size limestone might be an effective, low-cost method for mitigating acidity in certain streams.

8. ARNOLD, D. E. 1982. Vulnerability of waters of the Middle Atlantic States and their biota to acidification and its effects. Pages 73–75 *in* J. S. Jacobson, ed. Proceedings of the New York State symposium on atmospheric deposition. Center for

Environmental Research, Cornell University, Ithaca, N.Y.

Several projects in progress are described. These projects deal with either the assessment of vulnerability of Pennsylvania and Middle Atlantic States' waters to acidification, or the effects of acidification on various elements of the aquatic food chain, particularly invertebrate animals. The status of acid precipitation and its effects on Pennsylvania waters are described.

9. Arnold, D. E., P. M. Bender, A. B. Hale, and R. W. Light. 1981. Studies on infertile, acidic Pennsylvania streams and their benthic communities. Pages 15–33 *in* R. Singer, ed. Effects of acid precipitation on benthos. North American Benthological Society, Hamilton, N.Y.

Many Pennsylvania streams are exhibiting pH between 4.5 and 5.5 and alkalinity from 0 to 200 μeq/L. Rain pH is commonly between 3.8 and 4.0. In a moderately acidic (pH 5.2) stream, biomass, production, and species diversity of periphyton were not significantly different from those in an otherwise similar neutral (pH 6.8) stream. Species composition was significantly different, and the dry weight of periphyton was greater in the acidic stream. These differences may be due to favorable conditions for dominance by acid-tolerant species. Decomposition rates of leaves in the two streams were similar. Insect biomass in the acidic stream was less than 25% that of the neutral stream, the difference due primarily to a paucity of algivorous species in the acidic stream. Other streams, with pH consistently below 5, exhibited varied invertebrate diversity and biomass, with some being nearly lifeless.

10. Arnold, D. E., and M. A. Fajvan. 1985. Acid deposition research in the School of Forest Resources. Pages 2–5 *in* M. A. Fajvan, ed. Annual report of research and extension. School of Forest Resources, Pennsylvania State University, University Park. 31 pp.

Effects of acid rain on the freshwater resources of Pennsylvania are described, and research in progress, including mitigation studies, is summarized.

11. Arnold, D. E., and M. A. Friday. 1989. Fish community characteristics of Bruce Lake and limestone-treated White Deer Lake, 1984–1988. Pages II-1–II-45 *in* P. T. Bradt, ed. A biological and chemical evaluation of the impact of limestone addition to an acid-stressed lake in the Pocono Mountains. Final report to Pennsylvania Power and Light Company. Environmental Studies Center, Lehigh University, Bethlehem, Pa. 250 pp.

Water chemistry, bacteria, algae, macrophytes, zooplankton, benthic macroinvertebrates, and fish were monitored for 4 years in two lakes of the Pocono Mountain area of Pennsylvania. White Deer Lake was treated twice with pulverized limestone; once by spreading on the ice and once by slurry barge. Bruce Lake was left untreated for comparison. While both lakes exhibited signs of progressive acidification, it was greatly retarded in treated White Deer Lake. In addition, some shift toward a biotic community more characteristic of circumneutral lakes was noted in White Deer Lake.

12. Arnold, D. E., R. W. Light, and V. J. Dymond. 1980. Probable effects of acid precipitation on Pennsylvania waters. U.S. Environ. Prot. Agency, Ecol. Res. Ser. Rep., EPA-600/3-80-012. 26 pp.

Existing data bases were searched for water analyses taken from the same Pennsylvania location and separated by at least 1 year. Of 983 data sets, 314 cases had two or more water analyses data points. Of these, 107 or 34% showed a decrease in pH, alkalinity, or both. Average decrease in pH was 0.4 units with a maximum of 1.3 units. Average decrease in alkalinity was 15 mg/L with a maximum of 105 mg/L. Average time between samples was 8.5 years. In 58% of the 71 cases where pH and alkalinity decreased and fish data were available, the number of fish species present also decreased.

13. Arnold, D. E., R. W. Light, and E. A. Paul. 1985. Vulnerability of selected lakes and streams in the Middle Atlantic States to acidification: a regional survey. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.19). 133 pp.

In conjunction with a similar study in New England, 278 lakes and streams in the nine Middle Atlantic States (Delaware, Maryland, New Jersey, New York, North Carolina, Pennsylvania, Tennessee, Virginia, West Virginia) were surveyed. Results indicated that a large number of relatively undisturbed waters are already acidified or are vulnerable to acidification. Alkalinity is probably the most accurate and useful predictor of sensitivity to acidification. Several published models of acidification were tested and evaluated on the basis of the data, but their predictive value was not greater than that of alkalinity alone.

14. ARNOLD, D. E., W. D. SKINNER, AND D. E. SPOTTS. 1988. Evaluation of three experimental low-technology approaches to acid mitigation in headwater streams. Water Air Soil Pollut. 41:385–406. (This paper also published as pages 385–406 *in* R. W. Brocksen and J. Wisniewski, eds. Restoration of aquatic and terrestrial systems. Kluwer Academic Publishers, Dordrecht, The Netherlands. 500 pp.)

Three low-technology methods for neutralizing acidic stream water were tested in a Pennsylvania stream system with pH 4.5–5.3 and zero alkalinity. A barrier of wire gabions filled with limestone chunks was effective at first but lost neutralizing ability rapidly, primarily because of clogging and use of low-quality limestone. Gravity-fed baskets of soda ash (sodium carbonate) briquettes had excellent neutralizing capacity but proved difficult to maintain because of excessively rapid dissolution of the material. Water-drip tanks with the soda ash briquettes proved unsatisfactory because of coalescence of the material into an impervious mass when damp. Studies of benthic invertebrate drift and abundance associated with the soda ash treatments showed no significant effect in a few hours or in 60 days.

15. ASAP COORDINATING COMMITTEE, PUBLISHERS. 1980. Proceedings of the action seminar on acid precipitation. Toronto, Ontario, Canada, 1–3 November 1979. 315 pp.

Topics covered in these proceedings include acid rain emissions; damages and effects to aquatic ecosystems and vegetation; effects on parks, wilderness, and wildlife; socioeconomic effects; health effects; effects on agriculture and forestry; political and national perspectives on acid rain; energy and environmental goals; and technological options for solutions. The seminar was sponsored by various organizations and agencies to focus attention on the problem of acid rain and provide information to the public.

16. AVERY, M. L., AND R. K. SCHREIBER. 1979. The Clean Air Act: its relation to fish and wildlife resources. U.S. Fish Wildl. Serv., FWS/OBS-75/20.8. 17 pp.

Federal air quality legislation is reviewed, with special emphasis on the 1977 amendments to the Clean Air Act. Participation by fish and wildlife biologists in the implementation of provisions of the 1977 amendments is discussed, and future research needs are identified.

17. BARTON, B. A., G. S. WEINER, AND C. B. SCHRECK. 1985. Effect of prior acid exposure on physiological responses of juvenile rainbow trout (*Salmo gairdneri*) to acute handling stress. Can. J. Fish. Aquat. Sci. 42:710–717.

Juvenile rainbow trout (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*) exposed to acid conditions (pH 4.7–5.7) for 5 days had plasma cortisol affected slightly during initial exposure, but plasma glucose and hematocrit increased and plasma sodium decreased. Fish held at pH 4.7 and subjected to a 30-s handling stress had plasma cortisol rise to a peak of more than twice that in handled fish held at pH 6.6. Based on the cortico-steroid response, it was concluded that acid-stressed fish were more sensitive to additional handling. Although plasma glucose and plasma sodium were better indicators of chronic acid stress than plasma cortisol, the greater cortisol response to handling at low pH may be a useful method of detecting increased interrenal activity during early stages of environmental acidification.

18. BLANCHER, P. J., AND D. G. MCAULEY. 1987. Influence of wetland acidity on avian breeding success. Trans. N. Am. Wildl. Nat. Resour. Conf. 52:628–635.

This report presents findings from eastern North American studies of avian reproductive responses to wetland acidification. Possible mechanisms that link wetland acidity to effects on avian reproduction and breeding success are identified. Most of the studies present evidence that low food abundance is responsible for poorer reproduction in low-pH wetlands. The effects of metal toxicity and reduced food quality at low pH need more study.

19. BLEY, P. W. 1987. Age, growth, and mortality of juvenile Atlantic salmon in streams: a review. U.S. Fish Wildl. Serv., Biol. Rep. 87(4). 25 pp.

This report covers published and unpublished knowledge of the age, growth, and sources of mortality in juvenile Atlantic salmon (*Salmo salar*) in streams. A synopsis of current data on the life history of salmon during the juvenile portion of their life cycle is provided. Juvenile Atlantic salmon remain relatively stationary in the stream and feed on invertebrate drift. High mortality of eggs and alevins has been attributed to low pH. Other causes of mortality are discussed in relation to dissolved oxygen, depth and velocity, parasitism and disease, pollution, predation, and downstream migration.

20. BORGHI, L., AND D. ADLER. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats—forests. U.S. Fish Wildl. Serv., FWS/OBS-80/40.6. 86 pp.

This report synthesizes research results of the effects of air pollution on fish and wildlife resources inhabiting forest ecosystems. Factors determining the type and degree of effects and research needs are presented.

21. BRADT, P. T., AND D. E. ARNOLD. 1986. Fish can't hide from acid rain. Pages 77–88 *in* R. Crawford, ed. World record game fishes 1986. Yearbook, International Game Fish Association, Fort Lauderdale, Fla. 320 pp.

This article describes acid precipitation and regions of the United States receiving acid rain; provides a general description of the effects of acid rain on aquatic plants, invertebrates, fish, and the terrestrial ecosystem; and discusses possible mitigation measures. Research results on fish and fish populations are presented.

22. BRADT, P. T., D. E. ARNOLD, M. B. BERG, J. L. DUDLEY, J. A. REMENAR, D. S. BARRASSO, AND M. A. FRIDAY. 1989. Biology and chemistry of an acidic lake: summer 1981 to summer 1988. Arch. Hydrobiol. In press.

Deep Lake in the Pocono Mountain area of Pennsylvania exhibits very low pH (4.5–5.2) and no acid neutralizing capacity. The flora and fauna are depauperate, but some species are quite abundant. A trend of increasing acidity has been accompanied by shifts in relative species abundance in several biotic groups. The only surviving fish is the pumpkinseed (*Lepomis gibbosus*); its population is abundant but growth is very poor. Experimental manipulation of the pumpkinseed population indicates that poor water quality, rather than population dynamics factors, is responsible for the poor growth.

23. BRADT, P. T., M. B. BERG, D. S. BARRASSO, J. L. DUDLEY, D. E. ARNOLD, J. F. P. COTTER, P. B. MEYERS, JR., P. SITKOWSKI, AND R. N. WEISMAN. 1984. The biological and chemical impact of acid precipitation on Pocono Mountain lakes. Final report to Pennsylvania Power and Light Company. Department of Biology, Lehigh University, Bethlehem, Pa. 215 pp.

Three lakes in the Pocono Mountain area of northeastern Pennsylvania were sampled from spring 1981 to summer 1983 to examine the biological and chemical effects of acid precipitation. All three lakes, which ranged from circumneutral to acidic, showed changes related to acidification in both biology and chemistry. The most acidic lake (pH 4.4; alkalinity 0) now only supports pumpkinseeds (*Lepomis gibbosus*) and acid-tolerant invertebrate groups.

24. BRETT, M. 1984. The littoral zooplanktic communities of an acid and a nonacid lake in Maine. Pages 385–388 *in* J. Taggart, ed. Lake and reservoir management. U.S. Environ. Prot. Agency, EPA 440/5/84-001. 604 pp.

The zooplankton community of the acid lake is dominated by the adults and nauplii of the copepod, *Diaptomus minutus*, the large cladoceran, *Diaphanosoma brachyurum*, and the acid water rotifer, *Keratella taurocephala*. The nonacid lake is dominated by four zooplankters, *Diaptomus minutus*, *Bosmina coregonis*, *Keratella taurocephala*, and *K. cochlearis*. The density of 3 species of zooplankton was greater in the acid lake and the density of 10 species was greater in the nonacid lake. Three factors are probably responsible for these differences: (1) biotic changes caused by the absence of fish in the acid lake, (2) oligotrophication resulting from acidification and a shorter flushing time in the acid lake, and (3) toxic effects of acidification.

25. BROWN, J. M., AND C. D. GOODYEAR. 1987. Acid Precipitation Mitigation Program: research methods and protocols. U.S. Fish Wildl. Serv., NEC-87/27. 5 pp.

This report provides the criteria for selection of research sites, describes the Acid Precipitation Mitigation Program (APMP) experimental design criteria for lakes and streams, and defines the quality assurance, quality control, and data management programs. This report also details the APMP protocols for the collection and handling of water, sediment, and biological samples, and the chemical, physical, and biological analytical procedures necessary to ensure high quality data. These protocols provide the methodological and analytical consistency necessary for a multisite research program on liming.

26. BRUMBAUGH, W. G., AND D. A. KANE. 1985. Variability of aluminum concentrations in organs and whole bodies of smallmouth bass (*Micropterus dolomieui*). Environ. Sci. & Technol. 19:828–831.

Graphite furnace atomic absorption spectrophotometry was the method used to analyze

variability of aluminum concentrations in smallmouth bass (*Micropterus dolomieui*). Highly variable amounts of aluminum in the gastrointestinal tract led to bias when included in whole-body samples. Since aluminum concentrations in gut tissues were similar to whole bodies without gut content, removal of the gastrointestinal tract should reduce bias and variability without measurably altering the "true" whole-body aluminum concentration.

27. BUCKLER, D. R., AND P. M. MEHRLE. 1985. Influence of ambient pH on the toxicity of inorganic contaminant mixtures to east coast striped bass. Estuaries 8(2B):92A.

    Striped bass (*Morone saxatilis*) populations have declined along the east coast since the early 1970's. Results of recent laboratory and on-site studies indicate that the interactions of inorganic contaminants, especially aluminum and pH, could be responsible for significant mortality of young striped bass. Although several causes are still proposed for the decline in east coast striped bass, the interaction of pH and inorganic contaminants caused by acidic precipitation in poorly buffered areas of the Chesapeake Bay should be considered as a contributing factor.

28. BUCKLER, D. R., P. M. MEHRLE, L. CLEVELAND, AND F. J. DWYER. 1987. Influence of pH on the toxicity of aluminum and other inorganic contaminants to east coast striped bass. Water Air Soil Pollut. 35:97–106.

    The toxicity of aluminum and a mixture of inorganic contaminants to young striped bass (*Morone saxatilis*) in soft fresh water was demonstrated to be age- and pH-dependent. Toxicity of the contaminants increased with decreases of pH in test waters. The interaction between low pH from acid deposition and inorganic contaminants should be considered as a possible factor contributing to the decline in abundance of east coast striped bass.

29. BUKAVECKAS, P. A., AND C. T. DRISCOLL. 1989. Effects of whole-lake base addition on the optical properties of three clearwater acidic lakes. Can. J. Fish. Aquat. Sci. In press.

    Effects of base addition on light attenuation, absorption, and scattering were examined in relation to posttreatment changes in phytoplankton abundance and dissolved organic carbon (DOC) concentrations. Increases in phytoplankton abundance correspond to increases in light scattering the first summer after liming of the two most acidic lakes. At the less acidic lake a significant increase in attenuation occurred after liming, despite no change in chlorophyll. Reacidification of Cranberry Pond was accompanied by reduction in DOC and chlorophyll, followed by a gradual decrease in light attenuation and absorption. At Woods Lake, reductions in lake transparency correspond to increases in light absorption which are attributed to higher DOC concentrations. Results from lake liming experiments support the hypothesis that changes in either the photochemical properties of DOC or DOC concentrations are important mechanisms by which changes in lake acidity regulate transparency.

30. BULKOWSKI, L., W. F. KRISE, AND K. A. KRAUS. 1985. Purification of *Cyclops* cultures by pH shock (Copepoda). Crustaceana 48(2):179–182.

    Cyclops and *Daphnia* frequently inhabit the same bodies of water and are excellent foods for zooplantivorous fish. The authors' objective was to develop a physiological separation technique based on relative survival of both *Daphnia* and *Cyclops* in solutions adjusted to various pH's. *Daphnia* has repeatedly been shown to be sensitive to low pH. Acid toxicity tests on *Daphnia* demonstrated that a several-day exposure to pH 4.5 was lethal. The organism reportedly does not occur in lakes with a pH below 5.

31. CANFIELD, D. E. 1983. Sensitivity of Florida lakes to acidic precipitation. Water Resour. Res. 19:833–839.

    Data from a survey of 165 lakes in Florida were used to determine pH, total alkalinity, calcium hardness, and calcite saturation index values. Florida has a large number of lakes that are vulnerable to reductions in pH and alkalinity by acidic precipitation. Chlorophyll *a* concentrations, zooplankton abundance, and fisheries data suggest that Florida lakes may not be as biologically sensitive as the alkalinity and calcite indices suggest.

32. CANFIELD, D. E., AND M. V. HOYER. 1988. Regional geology and the chemical and trophic state characteristics of Florida lakes. Lake Reservoir Manage. 4:21–31.

    A survey of 165 Florida lakes was conducted between September 1979 and August 1980. Average lake pH values ranged from 4.1 to 9.2 and average total alkalinity concentrations ranged

from 0 to 204 mg/L as calcium carbonate. Although lake trophic states ranged from oligotrophic to hypereutrophic, Florida lakes as a group can be characterized as productive, softwater lakes. More than 75% of the sampled lakes had total alkalinity concentrations below 40 mg/L as calcium carbonate. The mineral composition of the lakes seems to be strongly related to Florida's geologic and physiographic development.

33. CLEVELAND, L. 1986. Biological indicators of the impacts of acid rain and inorganic contaminants on coldwater and warmwater fish. Completion report 886.08, U.S. Fish and Wildlife Service, National Fisheries Contaminant Research Center, Columbia, Mo. 12 pp.

This study concentrated on measuring inorganic contaminant-induced stresses in fish which could possibly affect survivability. Two metabolic responses to inorganic contaminants are known to exist: (1) lead inhibits delta-aminolevulinic acid dehydratase (ALAD) activity, and (2) metallothionein, a metal sequestering protein which binds inorganic chemicals (except lead) is thought to provide a protective role against the toxic effects of these chemicals by reducing the amount of free metal in tissues. Results showed liver ALAD activity measurement provided a better estimate of the effect of lead on bluegills (*Lepomis macrochirus*) than monitoring whole-body lead concentrations.

34. CLEVELAND, L. 1986. Remedial action to reverse reproductive failure caused by acid rain. Completion report 886.05, U.S. Fish and Wildlife Service, National Fisheries Contaminant Research Center, Columbia, Mo. 12 pp.

This study was conducted with warm- and cold-water fish species to determine the influences of acidity alone and the interactive effects of acidity, aluminum, and low calcium on survivability, health, and well-being of vulnerable populations. These studies were aimed at evaluating the feasibility of mitigation by liming.

35. CLEVELAND, L., E. E. LITTLE, S. J. HAMILTON, D. R. BUCKLER, AND J. B. HUNN. 1986. Interactive toxicity of aluminum and acidity to early life stages of brook trout. Trans. Am. Fish. Soc. 115:610–620.

Eggs and young brook trout (*Salvelinus fontinalis*) were exposed to Al, Ca, and pH conditions similar to those found in some headwaters in the northeastern United States. Adverse effects on mortality, growth, behavior, and biochemical responses of brook trout at pH 4.5 with or without 300 μg/L Al, and at pH 5.5 with 300 μg/L Al, would make survival improbable under similar conditions in nature.

36. CLEVELAND, L., E. E. LITTLE, R. H. WIEDMEYER, AND D. R. BUCKLER. 1989. Chronic no-observed-effect concentrations of aluminum for brook trout exposed in low calcium dilute acidic water. Page 137 *in* T. E. Lewis, ed. Environmental chemistry and toxicology of aluminum. Lewis Publishers, Inc., Chelsea, Mich.

The results of this study show that acidity, length of exposure, and the biological endpoints measured are critical factors for determining no-effect concentrations of aluminum for fish inhabiting dilute acidic waters. Behavioral and reproductive variables of brook trout (*Salvelinus fontinalis*) seem to be sensitive indicators of acid and aluminum stress; growth and mortality are more resistant variables.

37. COMMITTEE ON THE ATMOSPHERE AND THE BIOSPHERE. 1981. Atmosphere–biosphere interactions: toward a better understanding of the ecological consequences of fossil fuel combustion. National Academy Press, Washington, D.C. 263 pp.

The committee focused its attention on the following pollutants: sulfur and nitrogen compounds, trace metals, and organic substances. The understanding of patterns of emission, transport, deposition, and biological effects of these pollutants is incomplete, and a preliminary guideline is provided for integrated research. Described in detail are the magnitude and form of anthropogenic emissions, processes, and biological accumulation. A guide was developed to predict consequences of continued or accelerated pollution, and a case history was given of effects of acid rain. The committee recommended that United States agencies provide funding for scientific research, and, in particular, for the establishment of graduate training programs in ecotoxicology.

38. COOMBS, M. C. 1982. Mineral composition and growth rates of brook trout (*Salvelinus fontinalis*) in four Pennsylvania streams of different mineral content. M.S. thesis, Pennsylvania State University, University Park. 70 pp.

Summary of research on brook trout collected from streams of various pH, specific conductance, and

total alkalinity. Fish from low alkalinity streams had slower growth rates. There was a significant correlation between growth rate and pH levels.

39. CORN, P. S., AND R. B. BURY. 1987. The potential role of acidic precipitation in declining amphibian populations in the Colorado Front Range. National Acid Precipitation Assessment Program, Aquatic Effects Task Group Peer Review, New Orleans, La., 17–23 May 1987. 2:741–748.

    Surveys suggest that two amphibian species, leopard frogs (*Rana pipiens*) and boreal toads (*Bufo boreas*) in the Front Range of the Rocky Mountains have recently declined. A research program is outlined to determine the status of montane amphibians and to assess the role of acid precipitation in any declines.

40. CORN, P. S., H. W. STOLZENBURG, AND R. B. BURY. 1989. Acid precipitation studies in Colorado and Wyoming: interim report of surveys of montane amphibians and water chemistry. U.S. Fish Wildl. Serv., Biol. Rep. 89(40.26). 56 pp.

    Three years of surveys in northern Colorado and southern Wyoming indicate that leopard frogs (*Rana pipiens*) and boreal toads (*Bufo boreas*) have suffered major declines in numbers of populations. Embryos of these and other species survived laboratory exposure to lower pH than we measured in the field, indicating that acid precipitation alone was not the primary cause of the declines.

41. CROSS, D. 1984. Liming—a bridge over troubled waters? U.S. Fish Wildl. Serv., Fish Wildl. News November–December:5.

    This article briefly describes mitigation work being conducted by the U.S. Fish and Wildlife Service. The discussion primarily describes mitigation research being conducted by the National Ecology Research Center—Leetown (formerly the Eastern Energy and Land Use Team).

42. CROSS, D. 1986. Research and acid rain. U.S. Fish Wildl. Serv., Fish Wildl. News September–October:20.

    This article describes and updates information on the Acid Precipitation Mitigation Program (APMP) of the Fish and Wildlife Service. Site descriptions and research protocols are detailed.

43. DESGRANGES, J. L., AND M. L. HUNTER, JR. 1987. Duckling response to lake acidification. Trans. N. Am. Wildl. Nat. Resour. Conf. 52:636–644.

    This paper is a compilation of data from three studies on American black ducks (*Anas rubripes*) and draws general conclusions on how lake acidification affects the condition and growth of ducklings reared in these environments. Results indicate productivity, acidity, and competition with fish may affect duckling growth and survival.

44. DISTEFANO, R. J. 1987. Effects of acidification on the crayfish *Cambarus bartonii bartonii* in southern Appalachian streams. M.S. thesis, Virginia Polytechnical Institute and State University, Blacksburg. 88 pp.

    Selected population variables and life history events are described for the crayfish (*Cambarus bartonii bartonii*) in two first-order streams. Laboratory experiments were used to determine median lethal concentrations for sulfuric acid exposure, physiological effects, influence of ambient water temperature, and episodic events on molting. Acute laboratory lethality tests yielded LC50 values for pH below 3.0. Decreased water temperature resulted in increased acid tolerance of intermolt adults and increased survival time during severe acid exposure. Acid exposure of intermolt adults affected internal ion regulation. Episodic events did not appear to be a direct mortality problem.

45. DJALAL TANDJUNG, S., D. V. ROTTIERS, AND R. L. HERMAN. 1982. Histopathological studies on the effects of acid stress to brook trout *Salvelinus fontinalis* (Mitchell) in the presence of sublethal concentration of aluminum. Page 357 *in* R. E. Johnson, ed. Acid rain/fisheries. Proceedings of an international symposium on acidic precipitation and fishery impacts in northeastern North America, Cornell University, Ithaca, N.Y., 2–5 August 1981. American Fisheries Society, Bethesda, Md. 357 pp.

    Fingerling brook trout (*Salvelinus fontinalis*) were exposed to different concentrations of aluminum at pH 5.6. The "Basic Static Acute Toxicity Test Method" was used to determine the 96-h LC50 of brook trout to aluminum sulfate. Tissue from six organs was examined. The toxicity of aluminum increased in softer water. Histological damage was observed in the skin, lateral line canal, gills, kidney, liver, and muscle. Damage was most severe at the concentration of aluminum closest to or higher than the LC50. The organs of surviving fish appeared histologically normal after a 3-month recovery.

46. ELSBURY, R. M., AND W. H. GINGERICH. 1987. Effect of Cd^{++} treatment on whole body electrolyte composition of larval brook trout (*Salvelinus fontinalis*) in soft, acidic water. Meeting of the Division of Environmental Chemistry, American Chemical Society, New Orleans, La., 30 August–4 September 1987. 194:847–848.

Impaired ion regulation may be a major factor contributing to mortality in fish populations subjected to acid stress. This study tested whether cadmium, an antagonist of calcium metabolism in mammals, may further aggravate iono-regulatory dysfunction caused by chronic acid exposure. Results suggest that sublethal Cd^{++} toxicity is greatly enhanced at reduced pH, presumably because of greater bioavailability of the metal. Exposure to Cd^{++} at low pH significantly affected pre-hatch mortality, hatching success, growth, ossification, and net ion balance in developing embryo-larval brook trout. The substantial decrease in ossification and in whole body Ca^{++} content in Cd^{++} treated fish appears to support the hypothesis that Cd^{++} exposure can affect net Ca^{++} balance in developing brook trout.

47. FOWLER, D. L. 1985. Fish assemblage characteristics of acid-sensitive streams in the southern Appalachian Mountains. M.S. thesis, University of Georgia, Athens. 61 pp.

Twelve stream systems in the southern Blue Ridge Province were studied. Alkalinity values (28–108 μeq/L) indicate the streams would be classified as sensitive to acid deposition. Correlation coefficients between the abundance of each species and alkalinity and pH were not significant. Analysis of historical data on fish assemblages and present water quality suggests that substantial acidification effects on fish probably have not occurred in these streams. Though baseflow pH and alkalinity do not seem to influence fish assemblage characteristics in headwater streams of this region, it is possible that acute pH depressions following storms could affect fish.

48. FOWLER, D. L., M. J. VAN DEN AVYLE, AND M. HUDY. 1988. Fish assemblage characteristics of acid-sensitive streams in the southern Appalachian Mountains. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 41:126–135.

Relations between fish abundance, diversity, stream pH, and alkalinity were assessed to evaluate effects of acid precipitation on fish assemblages of southern Appalachian Mountain headwater streams. First- and third-order reaches of 12 streams were sampled. Assemblages exhibited low diversity and typically had low biomass. Statistically significant relations between fish biomass or diversity and stream sensitivity were not consistently detected. This suggests that acidification probably has not had a substantial effect on fish populations in headwater streams of this area.

49. FRASER, J. E., AND D. L. BRITT. 1982. Liming of acidified waters: a review of methods and effects on aquatic ecosystems. U.S. Fish Wildl. Serv., FWS/OBS-80/40.13. 189 pp.

A summary of current information is presented on liming and how it relates to aquatic habitats potentially affected by acidification. Primary emphasis is on the fishery resource. Appendixes include a summary of liming projects in the United States, a list of State, Federal, and private sector contacts, and a review and evaluation of liming methods.

50. FRASER, J. E., D. L. BRITT, J. D. KINSMAN, J. DEPINTO, P. RODGERS, H. SVERDRUP, AND P. WARFVINGE. 1985. APMP guidance manual. Volume II. Liming materials and methods. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.25). 197 pp.

Volume II describes many of the materials and methods used to neutralize acid surface waters and summarizes important technical aspects of those selected mitigation methods that may be employed in the Acid Precipitation Mitigation Program. Also contained in this volume is a decision assistance program called DEACID. This user-friendly program is designed to assist researchers and resource managers to evaluate and compare alternative application strategies and neutralizing agents in terms of costs, technical feasibility, and effectiveness in meeting water quality objectives.

51. FREDA, J. 1986. The influence of acidic pond water on amphibians: a review. Water Air Soil Pollut. 30:439–450.

Acidic pond water may influence reproduction of amphibians by direct mortality of embryos and larvae, or by disrupting trophic relations between amphibians and other aquatic organisms. The embryo is the most sensitive stage of development. Larvae are killed by disruption of Na and Cl balance. The toxicity of pond water is governed by

complex interactions of pH, temperature, and concentrations of Al, Ca, and organic acids. The relative importance of the different mechanisms of acidification of amphibian breeding sites is unknown.

52. FREDA, J., AND W. A. DUNSON. 1985. Field and laboratory studies of ion balance and growth rates of ranid tadpoles chronically exposed to low pH. Copeia 1985:415–423.

The effect of sublethal, chronic exposure of wood frog (*Rana sylvatica*) tadpoles to low environmental pH under natural conditions was investigated. Tadpoles from low pH ponds had lower body sodium, chloride, and water concentrations. These observations parallel similar studies on fish and demonstrate the effects of low environmental pH on larval anuran ionic regulatory mechanisms.

53. FREDA, J., AND W. A. DUNSON. 1985. The effect of acidic precipitation on amphibian breeding in temporary ponds in Pennsylvania. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.22). 85 pp.

This study assessed the effects of acid deposition on amphibians breeding in temporary ponds in Pennsylvania by investigating the lowest pH's at which embryos could hatch, the physiological effects of low pH on amphibian larvae, pond chemistry and the influence of rainfall on pond pH, and the effect of pond pH on embryonic survival and local distribution of Jefferson's salamander (*Ambystoma jeffersonianum*) and the wood frog (*Rana sylvatica*). At very low pH's, embryos stop development soon after exposure. Jefferson's salamander was intolerant of low pH and was absent from most acidic ponds. The wood frog was tolerant and was found in ponds with the lowest pH.

54. FREDA, J., AND W. A. DUNSON. 1985. The influence of external cation concentration on the hatching of amphibian embryos in water of low pH. Can. J. Zool. 63:2649–2656.

Amphibian embryos exposed to low-pH water were killed by two distinct mechanisms. Embryos stopped development at very low pH levels. At higher, but still lethal, pH levels, embryos curled and failed to hatch. Addition of Ca, Mg, or Na ions prevented early mortality of embryos, but increased concentrations of these ions also caused the curling defect.

55. FREDA, J., AND W. A. DUNSON. 1986. Effects of low pH and other chemical variables on the local distribution of amphibians. Copeia 1986:454–466.

The effect of low environmental pH on amphibians was studied in central Pennsylvania and the New Jersey Pine Barrens. Hatching success was variable at specific pond pH's, indicating significant interaction of pH with other chemical variables. Tadpoles of Fowler's toad (*Bufo woodhousei*) and Pine Barrens treefrog (*Hyla andersoni*) grew significantly slower when exposed to low pH.

56. FRITZ, E. S. 1980. Potential impacts of low pH on fish and fish populations. U.S. Fish Wildl. Serv., FWS/OBS-80/40.2. 14 pp.

This report provides up-to-date information on the effects of low pH on freshwater fish and shellfish. The discussion of direct mortality includes information obtained from laboratory experiments and field investigations. Several aspects of indirect mortality are discussed: susceptibility to disease, destruction or modification of osmoregulatory and ionoregulatory tissues, endocrine imbalance and genetic damage, changes in predator–prey relations, habitat degradation, and changes in the availability of toxic substances.

57. GAGEN, C. J., AND W. E. SHARPE. 1987. Influence of acid runoff episodes on survival and net sodium balance of brook trout (*Salvelinus fontinalis*) confined in a mountain stream. Ann. Soc. R. Zool. Belg. 117(suppl. 1):219–230.

Yearling brook trout confined at various sites up to 30 days experienced mortality during periods of low pH (to 4.53) and high dissolved aluminum concentration (>0.2 mg/L) when exposure duration exceeded 1 day. Observed brook trout toxicity was attributed to severe body sodium depletion caused by dissolved aluminum at pH levels which were otherwise nontoxic.

58. GAGEN, C. J., AND W. E. SHARPE. 1987. Net sodium loss and mortality of three salmonid species exposed to a stream acidified by atmospheric deposition. Bull. Environ. Contam. Toxicol. 39:7–14.

Brook trout (*Salvelinus fontinalis*) showed a net loss of sodium of 2.0–2.2%/h after an 8-h exposure to laboratory waters with little or no dissolved aluminum. Aluminum accelerated net sodium loss in brook trout at pH 5.0. Field experiments indicated substantial net sodium loss can occur in natural settings where aluminum concentration is high. Rainbow trout (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*) experienced a 35% net loss of sodium at ambient aluminum concentrations above 0.4 mg/L and pH 5.2–5.4.

59. GIBSON, J. H., J. N. GALLOWAY, C. SCHOFIELD, W. MCFEE, R. JOHNSON, S. MCCARLEY, N. DISE, AND D. HERZOG. 1983. Rocky Mountain acidification study. U.S. Fish Wildl. Serv., FWS/OBS-80/40.17. 137 pp.

The objectives of this study were to (1) determine the sensitivity of watersheds typical of the Rocky Mountain region and the relation between watershed sensitivity and geology and soils; (2) evaluate the extent of current acidification and the potential for increasing acidification with increasing nitrate and sulfate deposition; and (3) to evaluate these results in terms of effects on fish populations. High-elevation lakes and streams in the central Rocky Mountain region were found to be sensitive to acidic deposition. There was no documented effect on fisheries.

60. GLASS, N. R., D. E. ARNOLD, J. N. GALLOWAY, G. R. HENDREY, J. J. LEE, W. W. MCFEE, S. A. NORTON, C. F. POWERS, D. L. RAMBO, AND C. L. SCHOFIELD. 1982. Effects of acid precipitation. Environ. Sci. & Technol. 16:162A–169A.

A short-term assessment was performed to survey the extent of acid deposition effects and to assemble available knowledge useful in structuring a long-term research effort. Areas of the eastern United States geologically sensitive to acid precipitation were evaluated and mapped; soils in the eastern United States were appraised and mapped based on sensitivity to acid precipitation; historical changes in stream water chemistry were examined and compared with changes in fish populations; effects of simulated sulfuric acid rain on yields and foliage of major United States crops were assessed; and effects of simulated sulfuric acid rain on model hardwood forests and their soils were studied. Results are summarized in this paper and detailed in a series of U.S. Environmental Protection Agency publications.

61. GLOSS, S. P., C. L. SCHOFIELD, AND M. D. MARCUS. 1989. Liming and fisheries management guidelines for acidified lakes in the Adirondack region. Final report, U.S. Fish Wildl. Serv., NERC-89/27. xi + 71 pp.

This report provides State agencies and private landowners with guidelines useful in evaluating general options available for lake liming and for managing brook trout (*Salvelinus fontinalis*) populations in limed lakes. The report presents considerations necessary to determine whether to lime a lake; describes lake types appropriate for liming and the limitations of liming; lists approaches to determine the appropriate timing and dosages of basic materials for liming and reliming; summarizes results from the Extensive Liming Study; and presents stocking and management strategies for brook trout in limed Adirondack lakes. While the report focuses on neutralizing acidic lakes in the Adirondacks, many of the management implications can be extrapolated to other areas.

62. GLOSS, S. P., C. L. SCHOFIELD, AND R. E. SHERMAN. 1988. An evaluation of New York State lake liming data and the application of models from Scandinavian lakes to Adirondack lakes. U.S. Fish Wildl. Serv., NERC-88/04. 40 pp.

Limestone dissolution efficiencies and reacidification rates in 10 small Adirondack lakes were compared with Scandinavian model predictions of dissolution and reacidification. The simple two-box dilution model of reacidification satisfactorily predicted calcium loss rates, indicating the importance of hydrology as a factor controlling reacidification rates in these small limed lakes.

63. GLOSS, S. P., C. L. SCHOFIELD, AND R. L. SPATEHOLTS. 1987. Conditions for reestablishment of brook trout (*Salvelinus fontinalis*) populations in acidic lakes following base addition. Lake Reservoir Manage. 3:412–420.

Fish surveys and in situ bioassays using fingerling brook trout were conducted in two acidic lakes (Woods Lake, pH = 5.0, and Cranberry Pond, pH = 4.8) to determine whether fish were present and to determine whether fish can survive in acidic conditions. Woods Lake was stocked in the fall and overwinter survival of two age-classes of fish was determined. Emigration from the lake accounted for a small percentage of the 90% loss. Neither acclimation procedures nor experimental selection for acid tolerance improved survival. In situ bioassays were conducted before, during, and after calcium carbonate addition. No detrimental effects of liming on fish survival were observed. There was improved survival of both 0 and 1 brook trout after liming.

64. HAINES, T. A. 1980. Acidic precipitation. Fisheries 5(6):2–5.

This paper gives a brief history of the acid rain problem and identifies the areas of North America that are affected. A discussion on the

effects of acid rain on aquatic environments, fish, shellfish, and related organisms is presented, and areas where further research or action is needed are identified. Seven proposed actions are presented by the American Fisheries Society as necessary to address the acid rain problem.

65. HAINES, T. A. 1981. Acid precipitation and its consequences for aquatic ecosystems: a review. Trans. Am. Fish. Soc. 110:669–707.

Increased use of tall smoke stacks has promoted long-range transport of acidic gases containing metals and organic compounds that are subsequently deposited in acidic precipitation. Where acid-neutralizing capacity of soil and water is low, pH of lakes and streams is decreased. Aquatic organisms of all trophic levels have been affected.

66. HAINES, T. A. 1981. Acid rain fisheries research in the United States. Pages 103–112 *in* L. Sochasky, ed. Acid rain and the Atlantic salmon. Int. Atl. Salmon Found. Spec. Publ. Ser. 10. 171 pp.

This paper discusses, by performing organization and funding source, research projects addressing effects of acidic precipitation on fish. Major objectives and methods are described. Research needs not being met by the research projects are identified.

67. HAINES, T. A. 1981. Acid rain, the invisible threat. Maine Fish Wildl. 22(2):24–26.

This report provides a general description of acid rain, pH scale, and the causes of acid rain. Acid rain transport is also described. In addition, a brief discussion of the adverse effects of acid rain on aquatic systems and water quality is included. Several remedial and abatement techniques are briefly mentioned.

68. HAINES, T. A. 1981. Effects of acid rain on Atlantic salmon rivers and restoration efforts in the United States. Pages 57–63 *in* L. Sochasky, ed. Acid rain and the Atlantic salmon. Int. Atl. Salmon Found. Spec. Publ. Ser. 10. 171 pp.

A review of research findings on effects of acid rain on Atlantic salmon (*Salmo salar*). Many streams with salmon habitat are vulnerable to acidification due to low buffering capacity. Reestablishment or continued existence of self-sustaining populations could be adversely affected by acid rain.

69. HAINES, T. A. 1982. Comments: interpretation of aquatic pH trends. Trans. Am. Fish. Soc. 111:779–786.

The author discusses his views and interpretation of historic pH values and how these values affect noted trends in pH. Some of the literature is reviewed.

70. HAINES, T. A. 1982. Introduction to the acid rain/fisheries symposium. Pages 3–4 *in* R. E. Johnson, ed. Acid rain/fisheries. Proceedings of the international symposium on acidic precipitation and fishery impacts in northeastern North America, Cornell University, Ithaca, N.Y., 2–5 August 1981. American Fisheries Society, Bethesda, Md. 357 pp.

The author compares acid rain research in North America to that in Scandinavian countries. Long-term data are lacking in North American research. This symposium was scheduled to maximize the dissemination of new information resulting from acid rain research in North America and make the data available to the scientific community and the general public.

71. HAINES, T. A. 1983. Acid rain: acidification of headwater lakes and streams in New England. Pages 83–87 *in* J. Taggart, ed. Lake restoration, protection and management. U.S. Environ. Prot. Agency, EPA-440/5-83-001. 608 pp.

This paper describes a survey of 226 headwater lakes and streams in six New England States. Approximately half of the waters were judged to be vulnerable to acidification based on acid neutralizing capacity. Historical pH and alkalinity data indicate that waters have been acidified where acid neutralizing capacity is low.

72. HAINES, T. A. 1983. Organochlorine residues in brook trout from remote lakes in the northeastern United States. Water Air Soil Pollut. 20:47–54.

Organochlorine residues were compared among age groups of brook trout (*Salvelinus fontinalis*) and correlated by regression analyses with water chemistry factors that might be affected by acid precipitation.

73. HAINES, T. A. 1985. A survey of fish populations and water chemistry in remote, undisturbed Maine lakes: physiological and population level response. Page 93 *in* H. C. Martin, ed. Proceedings of the international symposium on acidic precipitation, Muskoka, Ontario, Canada, 15–20 September 1985.

Results of a survey of 22 Maine lakes are presented. Both water chemistry and endemic fish populations were studied. The most acid-tolerant fish species was brook trout (*Salvelinus fontinalis*; pH 5.0–7.0). Brook trout and white suckers (*Catostomus commersoni*) from acidic (pH) lakes contained higher concentrations of cadmium and mercury.

74. HAINES, T. A. 1985. Acid rain: international aspects. Pages 65–71 *in* P. M. Mehrle, Jr., R. H. Gray, and R. L. Kendall, eds. Toxic substances in the aquatic environment: an international aspect. American Fisheries Society, Bethesda, Md. 98 pp.

Acid precipitation has damaged or threatened aquatic resources in Canada, the Netherlands, Norway, Scotland, Sweden, and the United States. Differing jurisdictions at the acid sources and locations of damage complicate the assignment of costs for damage abatement.

75. HAINES, T. A. 1985. Acidic precipitation and fisheries effects in the northeastern U.S.: 1984 update. Pages 127–132 *in* F. Richardson and R. Hamre, eds. Wild Trout III, proceedings of the 1985 symposium, Yellowstone National Park, 24–25 September 1984.

The first reports of effects of acid deposition on fish populations were from the Adirondack region of New York. Subsequent investigations have confirmed the presence of acid lakes in remote areas of Maine, New Hampshire, New York, Rhode Island, and Vermont. Streams in Maine, New York, and Pennsylvania undergo a pH depression associated with snowmelt or rain. Surveys of fish populations revealed that the number of fish species declines with declining pH. It is not presently known whether the number of acidic lakes and streams in the Northeast is increasing, decreasing, or stable. Fishless lakes and streams exist in Maine, New Hampshire, New York, Pennsylvania, and Vermont.

76. HAINES, T. A. 1985. Fish species distribution as a function of lake acidity in the northeastern United States. Pages 63–82 *in* P. J. Rago and R. K. Schreiber, eds. Acid rain and fisheries: a debate of issues. Symposium proceedings of the 114th annual meeting of the American Fisheries Society, Cornell University, Ithaca, N.Y., 12–16 August 1984. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.21). 106 pp.

The northeastern United States now receives precipitation with an annual weighted mean pH of 4.3–4.4. A substantial portion of the surface waters in this region are low in alkalinity and are believed to be vulnerable to acidification. In order to test the hypothesis that acidic precipitation has reduced the pH of sensitive surface waters and resulted in the elimination of sensitive fish species, a survey was made of the water chemistry and fish populations of 20 lakes in Maine. There were no fish present in two lakes with pH 4.7–4.9. All other lakes with pH > 5.0 contained fish. There was no relation between the number of species or catch per unit effort (CPUE) and lake acidity for lakes that contained fish.

77. HAINES, T. A. 1986. Fish population trends in response to surface water acidification. Pages 300–334 *in* Acid deposition: long-term trends. National Academy of Science Press, Washington, D.C.

Fish survey data were used to evaluate the hypothesis that increased acidity of surface waters has reduced or eliminated fish populations in the Northeast. The strongest evidence consists of temporal association data from Adirondack mountain lakes and Nova Scotia rivers. These data show declines in acid-sensitive fish populations over the past 20–40 years. Data from Maine lakes, Vermont lakes, and Pennsylvania streams show that fish population status is related to present water chemistry. To rule out factors other than acidification in loss or decline of populations, intensive case-by-case studies are needed.

78. HAINES, T. A. 1987. Atlantic salmon resources in the northeastern United States and the potential effects of acidification from atmospheric deposition. Water Air Soil Pollut. 35:37–48.

Atlantic salmon (*Salmo salar*) were formerly abundant in northeastern coastal rivers. Most of the native Atlantic salmon rivers are low in acid neutralizing capacity and receive acid precipitation. In some first- and second-order streams in Maine, pH episodically declines to 4.7 and Al increases to 350 μg/g. These conditions could be toxic to sensitive early life stages of Atlantic salmon. Atlantic salmon populations in the United States have not been adversely affected by atmospheric deposition.

79. HAINES, T. A., AND J. J. AKIELASZEK. 1983. A regional survey of chemistry of headwater lakes and streams in New England: vulnerability to acidification. U.S. Fish Wildl. Serv., FWS/OBS-80/40.15. 141 pp.

This report describes results of a survey conducted of 226 headwater lakes and low-order

streams in six New England States. Physical and chemical variables were measured. It was concluded that alkalinity is the best measure of vulnerability to acidification.

80. HAINES, T. A., AND J. J. AKIELASZEK. 1983. Acid rain: acidification of headwater lakes and streams in New England. Pages 83–87 *in* J. Taggart, ed. Lake restoration, protection and management. U.S. Environ. Protect. Agency, EPA-440/5-83-001. 608 pp.

This is a report of the results of a survey of 226 headwater lakes and streams in six New England States to determine the status of surface waters with respect to acidification. Analyses included pH, alkalinity, specific conductance, color, calcium, and aluminum. Acidic waters (pH$<$5) were found in every State and composed 8% of the waters surveyed. About half the waters surveyed were judged to be vulnerable to acidification.

81. HAINES, T. A., AND J. J. AKIELASZEK. 1984. Effects of acidic precipitation on Atlantic salmon rivers in New England. U.S. Fish Wildl. Serv., FWS/OBS-80/40.18. 108 pp.

A water chemistry survey was conducted in nine Atlantic salmon (*Salmo salar*) rivers in New England. The pH and aluminum concentrations in second- and third-order streams were well within safe limits for Atlantic salmon. First-order streams reached levels of pH and aluminum concentration that may be toxic to sensitive early life stages or during smoltification.

82. HAINES, T. A., J. J. AKIELASZEK, S. A. NORTON, AND R. B. DAVIS. 1983. Errors in pH measurement with colorimetric indicators in low alkalinity waters. Hydrobiologia 107:57–61.

Laboratory studies compared colorimetric and electrometric pH results. Field studies used simultaneous colorimetric and electrometric pH determinations. Colorimetric indicators deviated from electrometric pH results at low alkalinities and near the end of their operating range. They agreed at alkalinities of 20 μeq/L and greater, or near the center of their operating range.

83. HAINES, T. A., AND J. P. BAKER. 1986. Evidence of fish population responses to acidification in the eastern United States. Water Air Soil Pollut. 31:605–629.

Present and historical fishery survey records were examined to investigate whether acidification has reduced or eliminated fish populations in areas of the eastern United States. The number of usable data sets was small. Trend analyses were limited by the lack of high quality historical data. The strongest evidence for fisheries declines associated with acidification was provided by data for the Adirondack mountain region of New York.

84. HAINES, T. A., AND M. L. HUNTER, JR. 1982. Waterfowl and their habitat: threatened by acid rain? Pages 177–188 *in* Proceedings of the fourth international waterfowl symposium, New Orleans, La., 30 January–1 February 1981.

The effects of acidic precipitation on waterfowl are little known, but they may include loss of food for birds, especially ducklings, that eat fish as well as those that eat aquatic invertebrates. Biomagnification of toxic elements in acidic lakes may also adversely affect waterfowl. The loss of fish from acidic lakes may benefit some waterfowl by reducing competition for invertebrates.

85. HAINES, T. A., C. H. JAGOE, F. J. DWYER, AND D. R. BUCKLER. 1987. Relation of trace metal body burdens and gill damage in fish to surface water acidification from atmospheric deposition. Pages 90–104 *in* R. Ryars, ed. Fate and effects of pollutants on aquatic ecosystems: proceedings of the USA–USSR symposium, Athens, Ga., 19–21 October 1987. U.S. Environ. Prot. Agency, EPA/600/9-88/001. 182 pp.

The possible relation between trace metal body burden in fish and various physical and chemical factors in lakes was examined. The effect of acidity-related variables on body burdens in brook trout (*Salvelinus fontinalis*) was determined. The effects of aluminum on gill structure of Atlantic salmon (*Salmo salar*) were studied under laboratory conditions to determine if a link exists between aluminum form and concentration and damage to gill structures.

86. HAINES, T. A., C. H. JAGOE, AND S. J. PAUWELS. 1985. Fish species distribution as a function of lake acidity in the northeastern United States. Pages 82–95 *in* P. J. Rago and R. K. Schreiber, eds. Acid rain and fisheries: a debate of issues. Symposium proceedings of the 114th annual meeting of the American Fisheries Society, Cornell University, Ithaca, N.Y., 12–16 August 1984. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.21). 106 pp.

A number of lakes in the northeastern United States are believed to be vulnerable to acidification from acid deposition. At least 17 lakes in the Adirondack

mountain region of New York are acidic and have lost fish populations. A survey of 28 Vermont lakes showed that the number of fish species and abundance was correlated with pH for lakes having pH < 6.0. A survey of 23 Maine lakes of similar size and drainage type showed mean pH values between 4.7 and 7.0. Lakes having pH 4.7–4.9 had no fish. All other lakes with pH 5.0 or greater had one or more species of fish. Fish abundance and number of species were significantly correlated with pH in lakes with pH < 6.0.

87. HAINES, T. A., C. H. JAGOE, AND S. J. PAUWELS. 1986. A comparison of gear effectiveness for fish population sampling in small Maine lakes. Preliminary report, U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis, Oreg. 7 pp.

    This project evaluated the effectiveness of several of the recommended fish sampling protocols for possible use in the National Surface Water Survey for small, northeastern lakes. The combination of gill nets and minnow traps effectively samples the fish populations of small Maine lakes.

88. HAINES, T. A., S. J. PAUWELS, AND C. H. JAGOE. 1986. Predicting and evaluating the effects of acidic precipitation on water chemistry and endemic fish populations in the northeastern United States. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.23). 139 pp.

    Fish populations of 22 lakes in Maine were studied. Lakes were selected that occurred in bedrock of high and low acid neutralizing capacity (ANC). Assessments of water chemistry, fish populations, trace element concentration, bone strength and composition, and gill histological variables were made. Results showed that areas of bedrock with high ANC did not contain acid lakes, but areas of bedrock low in ANC contained both neutral and highly acid lakes. Fish species distribution and abundance were affected by acidity. Fish from acidic lakes contained elevated concentrations of trace metals and showed sublethal stress that was evidenced by reduced bone mechanical strength and increased numbers of gill mucous cells.

89. HAINES, T. A., S. J. PAUWELS, C. H. JAGOE, AND S. A. NORTON. 1987. Effects of acidity-related water and sediment chemistry variables on trace metal burdens in brook trout (*Salvelinus fontinalis*). Ann. Soc. R. Zool. Belg. 117(suppl. 1):45–55.

    Lake water, surficial sediment, and brook trout were sampled in six small lakes in the northeastern United States with pH's ranging from 4.7 to 6.6. Surface sediments were enriched with Pb, Zn, and Cu, as compared with lakes not receiving acidic deposition. Concentrations of Al, Cd, Cu, Hg, Mn, Pb, and Se in brook trout differed significantly among lakes. Metal concentrations in fish were generally higher in the more acidic lakes.

90. HAINES, T. A., AND C. L. SCHOFIELD. 1980. Responses of fishes to acidification of streams and lakes in eastern North America. Pages 467–473 *in* J. Taggart, ed. Restoration of lakes and inland waters, an international symposium on inland waters and lake restoration, Portland, Maine, 8–12 September 1980. U.S. Environ. Prot. Agency, EPA-440/5-81-010. 552 pp.

    The pH of lakes and streams in eastern North America has declined. These changes in water quality adversely affect resident fish populations, reducing growth rate, increasing frequency of skeletal deformities, and eliminating sensitive species. The cause of declining fish populations in acidified waters has not yet been identified.

91. HALL, L. W., JR. 1987. Acidification effects on larval striped bass, *Morone saxatilis*, in Chesapeake Bay tributaries: a review. Water Air Soil Pollut. 35:87–96.

    Available data from in situ, on-site, and laboratory studies with striped bass in conjunction with water quality and contaminants data confirm that the eastern shore rivers of the Chesapeake Bay (Choptank, Nanticoke, and Pocomoke) are susceptible to acidic conditions. In 1984, acidification conditions (low pH, Al, low hardness) were documented in these systems at levels reported to cause high mortality to striped bass larvae. Striped bass populations in several western shore tributaries also seem to be vulnerable to acidic pH conditions. Though some spawning tributaries exhibit acidic conditions during spawning periods, other systems are resistant to acidification.

92. HALL, L. W., JR. 1988. Studies of striped bass in three Chesapeake Bay spawning habitats. Mar. Pollut. Bull. 19:478–487.

    Comparisons were made of in situ striped bass (*Morone saxatilis*) prolarval and yearling studies conducted in the Chesapeake and Delaware Canal (C&D Canal), the Nanticoke River, and the Potomac River. Cumulative survival of prolarvae in the Nanticoke River was less than 10%. Acidic conditions, aluminum, and soft fresh water (low buffering capacity) were suspected in causing the

poor prolarval survival. Cumulative survival in the C&D Canal was 42–59.5%. Cumulative survival of prolarvae in Potomac River water ranged from 4.5 to 22.5%. Poor survival was attributed to various inorganic contaminants (monomeric aluminum, cadmium, copper) and sudden decreases in water temperature.

93. HALL, L. W., JR., S. J. BUSHONG, M. C. ZIEGENFUSS, W. S. HALL, AND R. L. HERMAN. 1988. Concurrent mobile on-site and in situ striped bass contaminant and water quality studies in the Choptank River and upper Chesapeake Bay. Environ. Toxicol. Chem. 7:815–830.

In situ and mobile on-site prolarval and yearling survival studies were conducted in the Choptank River and the Chesapeake and Delaware Canal (C&D Canal) of the upper Chesapeake Bay. Chemical analyses of organic and inorganic contaminants in habitat water were performed and water quality variables monitored. Prolarval survival ranged from 30 to 45% after 96-h exposure to Choptank water, and control survival was greater than 74%. The following combination of conditions was potentially stressful to prolarvae: low hardness (36–48 mg/L $CaCO_3$), monomeric aluminum (0.150 mg/L), cadmium (0.003 mg/L), and copper (0.040 mg/L). Yearling survival in the on-site and in situ tests ranged from 93 to 100% in the control and Choptank River water after 9-day exposure. Survival of prolarvae in C&D canal water ranged from 52.5 to 70% after 96-h exposure. Yearling survival was 95% or greater in C&D Canal water and control water.

94. HALL, L. W., JR., W. S. HALL, S. J. BUSHONG, AND R. L. HERMAN. 1987. In situ striped bass (*Morone saxatilis*) contaminant and water quality studies in the Potomac River. Aquat. Toxicol. 10:73–99.

The authors' objectives were to evaluate survival of striped bass prolarvae and yearlings in the Potomac River by using in situ test chambers and to correlate survival of both striped bass life stages with the presence of water quality conditions and inorganic and organic contaminants. Water quality variables measured were temperature, salinity, dissolved oxygen, pH, conductivity, alkalinity, hardness, and turbidity. Poor survival (4.5–22.5%) of prolarvae was likely related to the presence of inorganic contaminants (monomeric aluminum, cadmium, and copper) acting singly or synergistically and to sudden decreases in water temperature ($< 11°C$). The data suggest that certain inorganic contaminants and water quality conditions were stressful to two life stages of striped bass.

95. HALL, L. W., JR., A. E. PINKNEY, R. L. HERMAN, AND S. E. FINGER. 1987. Survival of striped bass larvae and yearlings in relation to contaminants and water quality in the upper Chesapeake Bay. Arch. Environ. Contam. Toxicol. 16:391–400.

This study was designed to evaluate the survival of striped bass (*Morone saxatilis*) yolk-sac larvae and yearlings at three locations in their natural spawning habitat in the upper Chesapeake Bay, and correlate larval and yearling survival with the presence of 11 water quality variables (including temperature, salinity, dissolved oxygen, conductivity, pH, alkalinity, hardness, and turbidity), 10 inorganic contaminants, and 21 organic contaminants. The cumulative survival ranged from 42.0 to 59.5% for larvae after 96 h of exposure to habitat water. Survival in control conditions was 77.5 and 80.5%. All yearling striped bass survived 10 days of exposure to habitat water. Although habitat water was not acutely toxic, histological examination of surviving yearling striped bass indicated sublethal effects.

96. HALL, L. W., JR., A. E. PINKNEY, L. O. HORSEMAN, AND S. E. FINGER. 1985. Mortality of striped bass larvae and yearlings in relation to contaminants and water quality in a Chesapeake Bay tributary. Trans. Am. Fish. Soc. 114:861–868.

This study evaluates the effects of contaminants and water quality on survival of striped bass (*Morone saxatilis*) larvae in a natural spawning habitat. Organic and inorganic contaminants were monitored. Factors suspected as contributors to mortality were low pH, aluminum concentrations, and water softness.

97. HALL, R. J., AND D. B. PEAKALL. 1987. Acid rain effects on wildlife: some research perspectives. Trans. N. Am. Wildl. Nat. Resour. Conf. 52:605–607.

An introduction to a special session of the North American Wildlife and Natural Resources Conference on acidification and wildlife. The authors briefly review the background of wildlife research and effects of acidification, including the complexities involved. In addition, they stress the importance of the cooperation between United States and Canadian biologists.

98. HALSTEAD, B., AND J. C. TASH. 1982. Unusual diel pH's in water as related to aquatic vegetation. Hydrobiologia 96:217–224.

High diel pH's (> 9.0) showing little or no fluctuation were observed in several impoundments. This

phenomenon was experimentally produced in water that contained only *Myriophyllum spicatum* or filamentous algae. The ability of these plants to cause high diel pH's in water may have evolved in response to competition with phytoplankton for carbon.

99. HAMILTON, S. J., AND T. A. HAINES. 1989. Bone characteristics and metal concentrations in white suckers (*Catostomus commersoni*) from one neutral and three acidified lakes in Maine. Can. J. Fish. Aquat. Sci. 46:440–446.

    Bone characteristics of white suckers from four lakes were studied in relation to lake water quality and metal concentrations in fish. One lake had a neutral pH, high buffering capacity, and low aluminum concentrations; whereas the other three lakes had low pH, low buffering capacity, and elevated aluminum concentrations. Concentrations of aluminum in white suckers were not different among the four lakes, but concentrations of cadmium, lead, and mercury were elevated in fish from the three low-pH lakes. Vertebrae were weaker and more flexible in fish from the low-pH lakes.

100. HAMILTON, S. J., AND P. M. MEHRLE. 1986. Metallothionein in fish: review of importance in assessing stress from metal contaminants. Trans. Am. Fish. Soc. 115:596–609.

    Metallothionein plays an important role in the transport and storage of heavy metals. It provides protection against the toxic effects of these metals by sequestering and reducing the amount of free metal ions. Results of laboratory and field investigations show metallothionein synthesis is induced in fishes during chronic, but not acute, exposures to metals. The authors review the literature on metallothionein in fish and emphasize the protein's role in detoxification and binding of metal contaminants.

101. HAMILTON, S. J., P. M. MEHRLE, AND J. R. JONES. 1987. Cadmium-saturation technique for measuring metallothionein in brook trout. Trans. Am. Fish. Soc. 116:551–560.

    A mammalian technique was adapted for use with fish liver tissue to quantitate the amount of cadmium bound to unsaturated and cadmium-saturated metallothionein as a biological indicator of metal stress. The technique gave precise measurements of metallothionein in liver supernatant that were analyzed separately and quantified by atomic absorption or radiometry. Metallothionein was completely saturated with cadmium in fish injected with cadmium but was not saturated in fish exposed to waterborne cadmium for 30 days, although metallothionein was increased in the same exposure that had reduced survival (5 μg Cd/L).

102. HAMILTON, S. J., P. M. MEHRLE, AND J. R. JONES. 1987. Evaluation of metallothionein measurement as a biological indicator of stress from cadmium in brook trout. Trans. Am. Fish. Soc. 116:541–550.

    Measurement of metallothionein alone was not a useful indicator of cadmium toxicity in brook trout (*Salvelinus fontinalis*). A better biological indicator was the amount of free cadmium in liver tissue. The presence of free cadmium in tissues of brook trout suggests metallothionein was not saturated with cadmium before the appearance of pathological effects, conflicting with the "spillover" hypothesis.

103. HARAMIS, G. M., AND D. S. CHU. 1987. Acid rain effects on waterfowl: use of black duck broods to assess food resources of experimentally acidified wetlands. Pages 173–181 *in* A. W. Diamond and F. L. Filion, eds. The value of birds. Int. Counc. Bird Pres., ICBP Tech. Publ. No. 6.

    This paper describes the experimental use of pen-reared American black duck (*Anas rubripes*) broods and manmade emergent wetlands to assess the effects of acidification on black duck productivity. Eighteen broods (females with four 10-day-old ducklings) were exposed for 10-day trial periods on acidified (pH 5.0) and control (pH 6.8) wetlands. Impaired growth and survival of ducklings was evident on acidified wetlands.

104. HILL, J., R. E. FOLEY, V. S. BLAZER, R. G. WERNER, AND J. E. GANNON. 1988. Effects of acidic water on young-of-the-year smallmouth bass (*Micropterus dolomieui*). Environ. Biol. Fishes 21:223–229.

    To determine if smallmouth bass populations may be lost directly from acid effects, a laboratory study on the effects of acid exposure on growth, survival, and histology of young smallmouth bass (3–36 days post-swimup) was performed. Fish were exposed to declining, then fluctuating pH levels averaging pH 7.4 (control), 5.7, and 5.0. Substantial decreases in survival, as well as tissue damage, were observed. Histological analysis revealed severe changes in fish exposed to the most acidic treatment, with damage to blood, gill, and epithelial tissue. Growth was less useful as an

indicator of response to acidity. Results suggest that an increase in environmental acidity is sufficient to cause losses in this species, even in the absence of synergists such as heavy metals.

105. HOWELLS, G., AND T. A. HAINES. 1982. Comments: interpretation of aquatic pH trends. Trans. Am. Fish. Soc. 8:779.

Two viewpoints on the interpretation of historic trends in lake acidification are presented. Uncertainties in pH measurement encompass the following: the addition of unknown quantities of chemical colorimetric indicators to waters influenced pH reported in the past; modern glass-electrode measurements have different geometries; and measuring the potential between a low-ionic-strength medium and the liquid junction has an inherent error of 0.2 pH unit. Careful reporting and cautious interpretation of field and laboratory observations are urged.

106. HUDY, M., M. J. VAN DEN AVYLE, AND D. FOWLER. 1985. Fish community structure in potentially acid-sensitive streams of the southern Blue Ridge Province. Final report, U.S. Environmental Protection Agency. Coop. Agreement No. 14-16-0009-1598. 20 pp.

This project is part of a multiagency cooperative research effort dealing with potential acidification effects on biological communities in streams of the southern portion of the Blue Ridge Province. Sampling sites, sampling design, and field sampling of water quality and fish communities are described.

107. HUNN, J. B. 1985. Role of calcium in gill functions in freshwater fishes. Comp. Biochem. Physiol. 82A:543–547.

The role of external Ca on the ionic and osmoregulatory function of the gills of freshwater fishes is reviewed. A competition for binding sites on the gill between Ca and other divalent or trivalent metallic ions influences their uptake and toxicity to fish. Ca and Al are the two ions that most affect fish survival at low pH.

108. HUNN, J. B., L. CLEVELAND, AND E. E. LITTLE. 1987. Influence of pH and aluminum on developing brook trout in low calcium water. Environ. Pollut. 43(1):63–73.

Eyed brook trout (*Salvelinus fontinalis*) embryos were exposed to pH's of 4.5, 5.5, and 7.5 with and without aluminum. Embryo mortality exceeded 80% at pH 4.5, 15–18% in pH 5.5, and less than 2% in pH 7.5. Aluminum significantly reduced embryo mortality at pH 4.5 but did not affect mortality at pH 5.5 or 7.5. Percent hatch and poor hatch were pH-dependent and were not significantly influenced by aluminum.

109. HUNTER, M. L., JR., J. J. JONES, K. E. GIBBS, AND J. R. MORING. 1986. Duckling responses to lake acidification: do black ducks and fish compete? Oikos 47:26–32.

Two pairs of physically similar ponds with different acidities were studied in Maine. The acidic ponds were fishless; the circumneutral ponds had fish. American black duck (*Anas rubripes*) ducklings grew faster on the acidic ponds, while behavior differences also indicated the acidic ponds were better duckling habitat. There was overlap of brook trout (*Salvelinus fontinalis*) and duckling diets with two of the three indices calculated indicating that ducklings on the circumneutral ponds had diets more similar to fish than ducklings on the acidic ponds. Sampling for invertebrate abundance indicated the presence of fish decreased invertebrate abundance. Results indicate that ducklings and fish compete for invertebrates.

110. HUNTER, M. L., JR., J. J. JONES, K. E. GIBBS, J. R. MORING, AND M. BRETT. 1985. Interactions among waterfowl, fishes, invertebrates, and macrophytes in four Maine lakes of different acidity. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.20). 80 pp.

There was substantial overlap in the diet of brook trout (*Salvelinus fontinalis*) and American black ducks (*Anas rubripes*), supporting the hypothesis that ducklings and fish compete for invertebrates, and that, under certain circumstances, the negative effect of acidification on fish may produce a beneficial effect for ducklings.

111. HUNTER, M. L., JR., J. J. JONES, J. W. WITHAM, AND T. M. MINGO. 1986. Biomass and species richness of aquatic macrophytes in four Maine (USA) lakes of different acidity. Aquat. Bot. 24(1):91–95.

Macrophyte communities of two pairs of oligotrophic headwater lakes of different acidities are described. The acidic lakes had fewer species than the circumneutral lakes.

112. JAGOE, C. H., AND T. A. HAINES. 1983. Alterations in gill epithelial morphology of yearling Sunapee trout exposed to acute acid stress. Trans. Am. Fish. Soc. 112:689–695.

Fish exposed to acidified water at pH levels above those causing acute mortality showed little alteration in gill morphology. Acute lethal levels caused considerable damage to gill epithelia. Gill alterations may decrease the surface area available for gas exchange and contribute to the anoxia that seems to be an important source of mortality at very low pH.

113. JAGOE, C. H., AND T. A. HAINES. 1985. Fluctuating asymmetry in fishes inhabiting acidified and unacidified lakes. Can. J. Zool. 63:130–138.

Fluctuating asymmetry has been used in studies to quantify stress during early life. This study investigates a tie between environmental acidification and fluctuating asymmetry as a sign of acid-induced stress in fish.

114. JAGOE, C. H., T. A. HAINES, AND D. R. BUCKLER. 1987. Abnormal gill development in Atlantic salmon (*Salmo salar*) fry exposed to aluminum at low pH. Ann. Soc. R. Zool. Belg. 117(suppl. 1):375–386.

Scanning electron microscopy revealed gill abnormalities in fish exposed to 75 μg/L aluminum or more. These included poorly developed or absent secondary lamellae, fused primary lamellae, proliferation of epithelial cells, and an increased number of surface pits. Such effects were not noted in fish raised in aluminum-free water, regardless of pH. Aluminum interferes with normal gill development, resulting in poorly formed or nonfunctional gills.

115. JAGOE, C. H., T. A. HAINES, AND F. W. KIRCHEIS. 1984. Effects of reduced pH on three life stages of Sunapee char, *Salvelinus alpinus*. Bull. Environ. Contam. Toxicol. 33:430–438.

Water acidified to pH 3.0 killed all yearlings in less than 4 h. A pH of 3.5 was also fatal, survival times ranging from 16.5 to 19.0 h. Gills were coated with mucus and there was also considerable mucus on body surfaces. A pH of 4.0 was lethal to most yearlings. All sac fry died in pH 4.0, half died at pH 4.5. All eggs died in water of pH 4.0 after 53 h, at pH 4.5 after 96 h, and 40–60% of eggs died at pH 5.0 by the end of the experiment (198 h). Yearlings were the most resistant to acid stress; eggs the most sensitive.

116. KANE, D. A., AND C. F. RABENI. 1987. Effects of aluminum and pH on the early life stages of smallmouth bass (*Micropterus dolomieui*). Water Res. 21:633–639.

Recently hatched smallmouth bass were exposed to pH levels ranging from 5.1 to 7.5, with aluminum concentrations ranging from 32 to 1,000 μg/L. Acute bioassays at pH 5.1 and aluminum concentrations 180 μg/L and greater resulted in total mortality. Chronic toxicity tests at three pH levels and two aluminum concentrations showed survival was significantly lower at pH 5.1 and 5.7 with aluminum than in other treatments. Fish exposed to a pH of 5.1 without aluminum had intermediate survival, while fish at pH 5.7 and 7.3 without aluminum and pH 7.3 with aluminum had high survival.

117. KERCHER, J. R., AND M. C. AXELROD. 1981. SILVA: a model for forecasting the effects of SO_2 pollution on growth and succession in a western coniferous forest. Lawrence Livermore Laboratory, University of California, Livermore, Doc. No. UCRL-53109. 72 pp.

A forest succession simulator, SILVA, was developed for the mixed conifer forest type of the Sierra Nevada of California to simulate the effects of SO_2 on forest dynamics. SILVA was developed by modifying a northeastern United States forest succession simulator.

118. LASIER, P. J. 1986. The use of benthic macroinvertebrates as indicators of acid sensitivity in headwater streams of the southern Blue Ridge Province. M.S. thesis, University of Georgia, Athens. 206 pp.

The author's objective was to evaluate the feasibility of using characteristics of benthic macroinvertebrate assemblages as quantitative indicators of stream sensitivity to acidic deposition. Macroinvertebrate populations were sampled from first- and third-order reaches of 28 streams. The pH of these streams ranged from 5.65 to 7.15 and alkalinity from 10 to 205 μeq/L at first-order sites, and from pH 6.40 to 7.15 and alkalinity 23 to 168 μeq/L at third-order sites. Some information on macroinvertebrate assemblages showed their potential as indicators of acid sensitivity and as tools for predicting alkalinity and further classifying southern Blue Ridge Province headwater streams. Certain macroinvertebrate taxa could be used to determine the sensitivity of headwater streams to acidic deposition.

119. LEMLY, A. D., AND R. J. F. SMITH. 1987. Effects of chronic exposure to acidified water on chemoreception of feeding stimuli in fathead minnows *Pimephales promelas*: mechanisms and

ecological implications. Environ. Toxicol. Chem. 6:225–238.

A computer-automated behavioral assay was used to assess the effects of reduced ambient pH on the response of fathead minnows (*Pimephales promelas*) to chemical feeding stimuli. Twenty-five adult minnows were tested after exposure to one of five pH levels: 8.0, 7.0, 6.5, 6.0, and 5.5. Complete elimination of the feeding response occurred at pH 6.0 and lower; responses at higher pH levels were not statistically different from the controls. To test for possible recovery, minnows that did not respond at pH 6.0 were placed in water of control pH (8.0) for 24 h and then tested again. A statistically significant response to the feeding stimulus was restored. The results indicate that acute and chronic sublethal levels of acidification caused a reversible impairment of chemoreception and that the impairment can occur at a relatively high pH. The results correspond well with environmental studies that show fathead minnows are eliminated from natural waters when pH reaches 5.8–6.0.

120. LIGHT, R. W. 1983. Growth and reproductive ecology of the eastern brook trout, *Salvelinus fontinalis*, in streams of differing vulnerability to acidic atmospheric deposition. Ph.D. thesis, Pennsylvania State University, University Park. 198 pp.

Brook trout populations were compared on basis of growth, relative condition, and reproduction in three infertile streams with differing vulnerability to acidification. Brook trout from the least fertile stream showed the slowest growth. Fish from the most fertile stream had the highest relative condition. Trout from the least fertile stream showed a significant increase in relative condition after the population decreased from 223 to 91, while length stayed fairly constant.

121. LONGCORE, J. R., D. G. MCAULEY, K. L. STROMBORG, AND G. L. HENSLER. 1985. Effects of acidic precipitation on waterbirds in Maine. Trans. Northeast Sect. Wildl. Soc. 42:197.

Waterbird use and number of broods were recorded for 29 wetlands in east-central Maine, underlain with bedrock of low acid neutralizing capacity (ANC). Use of wetlands by 21 species that were observed >25 times was greater ($P<.0001$) for downstream (84%) versus headwater wetlands (16%). Headwater wetlands, which are most vulnerable to acidification in the low ANC areas, are used mostly by common goldeneyes (*Bucephala clangula*) and common loons (*Gavia immer*). Common mergansers (*Mergus merganser*), spotted sandpipers (*Actitis macularia*), and chimney swifts (*Chaetura pelagica*) used headwater wetlands about equally. The majority of species used wetlands classified as downstream or beaver-created. The data suggested that use of wetlands by birds is influenced more by morphometric and vegetative characteristics than by water chemistry. Nevertheless, large numbers of a variety of birds are associated with wetlands underlain with bedrock that has little or no capacity to neutralize acidic deposition.

122. LONGCORE, J. R., D. G. MCAULEY, T. M. MINGO, AND C. REID. 1987. Macroinvertebrate taxa and wetland pH: importance to waterbirds. Bull. N. Am. Benthol. Soc. 4(1):106.

Invertebrates were collected in 10 Maine wetlands, half with pH < 5.5 and half with pH > 5.5. The mean number of Insecta was variable among ponds, but higher on beaver-created, palustrine wetlands (158) than on glacial created, lacustrine wetlands (63). Fewer classes and orders of invertebrates ($P < 0.05$) occurred on ponds in the lower pH group. Some acid-tolerant taxa (Diptera, Hemiptera, Trichoptera) were relatively abundant on low-pH wetlands, while several other taxa (Basommatophora, Cladocera, Ephemeroptera, Isopoda) important to waterfowl were lower. The abundance of macrophytes influenced invertebrate numbers, but the degree of eutrophication of wetland water was more important. Decreases in some invertebrate taxa and increases in others in aquatic food webs may affect survival of young birds through reductions in food availability.

123. LONGCORE, J. R., R. K. ROSS, AND K. L. FISHER. 1987. Wildlife resources at risk through acidification of wetlands. Trans. N. Am. Wildl. Nat. Resour. Conf. 52:608–618.

This paper focuses on the common loon (*Gavia immer*), common merganser (*Mergus merganser*), osprey (*Pandion haliaetus*), common goldeneye (*Bucephala clangula*), American black duck (*Anas rubripes*), ring-necked duck (*Aythya collaris*), and hooded merganser (*Lophodytes cucullatus*) that breed in eastern North America and are at potential risk from acidic deposition. About 17% of the area evaluated was sensitive to acidic deposition based on bedrock buffering capacity. The majority of American black duck breeding range lies in areas affected by acid

deposition. Changes in invertebrate populations may affect the different bird species.

124. MANNY, B. A. 1980. Acid rain and runoff increase nutrients in northwestern Lake Huron. Coastal Oceanography and Climatology News 2(2):17.

Nutrient loading from the atmosphere may be a serious problem in Lake Huron, Lake Michigan, and Lake Superior, because water retention times in these large lakes are 20–185 years.

125. MANNY, B. A., G. L. FAHNENSTIEL, AND W. S. GARDNER. 1987. Acid rain stimulation of Lake Michigan phytoplankton growth. J. Great Lakes Res. 13:218–223.

Laboratory experiments demonstrated that additions of rainwater to epilimnetic lake water collected in southeastern Lake Michigan stimulated chlorophyll *a* production during incubations of 12–20 days. The stimulation caused by additions of rain acidified to pH 3.0 was greater than that caused by additions of untreated rain (pH 4.0–4.5). Results support the following: (1) acid rain stimulates phytoplankton growth in lake water, and (2) phosphorus in rain seems to be the factor causing stimulation. Acid rain may accelerate growth of epilimnetic phytoplankton in Lake Michigan and other oligotrophic lakes during stratification when other sources of bioavailable phosphorus to the epilimnion are limited.

126. MAYER, K. S., E. P. MULTER, AND R. K. SCHREIBER. 1984. Acid rain: effects on fish and wildlife. U.S. Fish Wildl. Serv., Fish Wildl. Leafl. 1. 9 pp.

This leaflet provides a brief background on what acid rain is and its causes, which areas in the United States are susceptible to acid rain, possible effects to aquatic resources and wildlife, and several types of mitigation strategies.

127. MCAULEY, D. G. 1986. Ring-necked duck productivity in relation to wetland acidity: nest success, duckling diet and survival. M.S. thesis, University of Maine, Orono. 81 pp.

Nest productivity, duckling food habits and brood and duckling survival of ring-necked ducks (*Aythya collaris*) were examined in relation to wetland water chemistry in east-central Maine. Class Ia–IIa ducklings from high-pH wetlands ate more invertebrate foods than ducklings from lower-pH wetlands. Ducklings on high-pH wetlands ate 33 different invertebrate taxa while only 17 taxa were eaten by ducklings on low-pH wetlands. Survival of ducklings was lower on low-pH wetlands than on high-pH wetlands. Class IIb–III ducklings from the lowest pH (<5.0) wetlands had the lowest daily survival rates.

128. MCAULEY, D. G., AND J. R. LONGCORE. 1988. Foods of juvenile ring-necked ducks: relationship to wetland pH. J. Wildl. Manage. 52:177–185.

Foods of 37 juvenile ring-necked ducks (*Aythya collaris*) from 16 different wetlands were examined in east-central Maine. Diets of ducklings from high-pH wetlands were more diverse than those from low-pH wetlands and consisted of 33 invertebrate taxa. On low-pH ponds only 17 taxa were eaten by ducklings. Class Ia–IIa ducklings from high-pH wetlands ate a greater proportion of invertebrates (77%) than ducklings from lower-pH wetlands (61%), though the difference was not significant ($P = 0.21$).

129. MCAULEY, D. G., AND J. R. LONGCORE. 1988. Survival of juvenile ring-necked ducks on wetlands of different pH. J. Wildl. Manage. 52:169–176.

Brood and duckling survival of ring-necked ducks (*Aythya collaris*) was examined in relation to wetland water chemistry in east-central Maine. Survival rates of broods and ducklings did not differ among wetlands of high and low alkalinities. Daily survival rate of ducklings was lower on low-pH wetlands than on high-pH wetlands. Ducklings 25–45 days old from the lowest pH wetlands had the lowest daily survival rate, while same-age ducklings from the highest-pH wetlands had the highest daily survival rate.

130. MCAULEY, D. G., AND J. R. LONGCORE. 1989. Nesting phenology and success of ring-necked ducks in east-central Maine. J. Field Ornithol. 60:112-119.

Selected aspects of the nesting biology of ring-necked ducks (*Aythya collaris*) in east-central Maine were studied during 1983–85 and compared to the results from previous studies. Nesting chronology, clutch size, and hatching success were similar to results reported from previous studies, but nest success was 32–42% lower. Among unsuccessful nests, predation (66.6%) and flooding (23.8%) caused most failures. Early nesting attempts varied each year with amount of rainfall in May and resulting water levels. Females nesting on acidic ($\text{pH} < 6.0$) wetlands and on wetlands of higher pH had similar nest success, clutch size, and renesting effort.

131. McFadden, J. F., W. L. Pennington, and E. L. Morgan. 1986. Applications of remote automated biomonitoring to Laurel Branch liming effects study. Page 46 *in* H. Olem, ed. Proceedings of the third annual acid rain conference for the southern Appalachians, Gatlinburg, Tenn., 27 October 1986.

Automated biomonitoring provides a means for measuring in situ fish breathing rate changes to episodic rain events. The system uses remote computer-assisted data collection platforms (DCP's) and satellite data retrieval options. Field studies were designed to test several types of fish-holding chambers and breathing rate monitors before linking the system to streamside DCP's. Results were used to construct trout breathing-rate detectors and to implement six of these devices at each of two water quality DCP's located along Laurel Branch. Remote stations are being used to fulfill real-time data needs as part of a 5-year study by the U.S. Fish and Wildlife Service to evaluate possible ecological changes to mitigative liming.

132. McKee, M. J., C. O. Knowles, and D. R. Buckler. 1989. Effects of aluminum on the biochemical composition of Atlantic salmon. Arch. Environ. Contam. Toxicol. 18:243–248.

Biomolecule content, dry weight, and wet weight of Atlantic salmon (*Salmo salar*) were monitored. Salmon exposed to various concentrations of aluminum were evaluated for growth, survival, and biochemical effects. By day 60, growth and survival were significantly reduced at the two highest aluminum concentrations. RNA and DNA were the most sensitive biomolecules monitored and were significantly reduced at the three highest aluminum concentrations. Biomolecule content or ratios were not particularly sensitive indicators of growth effects in Atlantic salmon exposed to aluminum.

133. McNicol, D. K., B. E. Bendell, and D. G. McAuley. 1987. Avian trophic relationships and wetland acidity. Trans. N. Am. Wildl. Nat. Resour. Conf. 52:619–627.

The authors summarize findings of studies investigating the relation between bird diets and wetland acidity. They address three major effects of wetland acidity on bird diets: (1) loss of fish, (2) altered predator–prey relations, and (3) loss of acid-sensitive invertebrates, including calcium-rich foods. Under acidic conditions, ducklings of several species became increasingly reliant on a few insect taxa that are abundant in acid waters. The negative effect of reduced acid-sensitive prey may be balanced by an increase in densities of some insects where competing fish populations are reduced.

134. Mirsky, E. N., and D. Harper. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats—deserts and steppes. U.S. Fish Wildl. Serv., FWS/OBS-80/40.9. 38 pp.

This report describes the features of desert and steppe ecosystems that determine the sensitivity of these ecosystems to air pollution. Data related to the effects of air pollutants on biota and whole ecosystems are reviewed. General information based on studies in other ecosystems is included.

135. Morgan, E. L., K. W. Eagelson, T. P. Weaver, and B. G. Isom. 1986. Linking automated biomonitoring to remote computer platforms with satellite data retrieval in acidified streams. Pages 84–91 *in* B. G. Isom, S. D. Dennis, and J. M. Bates, eds. Impact of acid rain and deposition on aquatic biological systems. Am. Soc. Test. Mater. STP 928.

Automated biosensing provides a method for measuring in situ breathing rate changes to stream episodes. Results were used to design groups of automated biosensing devices for detecting rainbow trout (*Oncorhychus mykiss*, formerly *Salmo gairdneri*) breathing rate responses and to implement eight units at each of two data collection water quality stations located along a stream subject to acid precipitation influences in the southern Appalachians.

136. Morgan, E. L., R. C. Young, and J. R. Wright, Jr. 1988. Developing portable computer-automated biomonitoring for a regional water quality surveillance network. Pages 127–141 *in* D. Gruber and J. Diamond, eds. Automated biomonitoring: living sensors as environmental monitors. J. Wiley & Sons, New York.

Two satellite data-linked remote water quality data collection platforms (DCP's) are being run on Laurel Branch in the southern Appalachian Mountains of Tennessee. The DCP's are equipped with six biosensing devices designed to record trout breathing responses. This program was initiated in 1985 by the U.S. Fish and Wildlife Service as part of the the National Acid Precipitation Assessment Program to evaluate stream ecological responses to regulated liming practices.

137. NEWMAN, J. R. 1980. Effects of air emissions on wildlife resources. U.S. Fish Wildl. Serv., FWS/OBS-80/40.1. 32 pp.

This report summarizes the known effects of air emissions on vertebrate wildlife resources. Wildlife are indirectly affected by contamination of their food resources and by habitat loss. Air emissions have caused mortality, injury, disease, and lowered resistance to stress. Some implications for wildlife management in regions affected by air emissions are discussed.

138. NEWMAN, J. R., AND R. K. SCHREIBER. 1984. Animals as indicators of ecosystem responses to air emissions. Environ. Manage. 8:309–324.

This paper reviews the reported responses of ecosystems to airborne pollutants and discusses the use of animals as indicators of ecosystem responses to these pollutants. Information is presented to show the importance of animals as indicators of ecosystem responses to air quality degradation, and their value as air pollution indices; that is, as air quality related values (AQRV), which are required in current air pollution regulations.

139. NEWMAN, J. R., AND R. K. SCHREIBER. 1985. Effects of acidic deposition and other energy emissions on wildlife. A compendium. Vet. Hum. Toxicol. 27:394–401.

This paper is a review of studies showing potential problems for wildlife populations from energy emissions. Information on effects of selected gaseous and particulate energy emissions on domestic animals, livestock, and on vertebrate wildlife is compared.

140. NEWMAN, J. R., AND R. K. SCHREIBER. 1988. Air pollution and wildlife toxicology: an overlooked problem. Environ. Toxicol. Chem. 7:381–390.

This paper reviews the present understanding of air pollution and wildlife toxicology and the continuing threat of airborne pollutants to wildlife. Available information on reported effects to vertebrate wildlife from major gaseous and particulate pollutants (sulfur dioxide, hydrogen sulfide, oxidants, arsenic, cadmium, fluoride, lead, and selenium) along with similar toxicological data for domestic animals is summarized. Information and information gaps on the toxic effects, tolerance levels, pathways of contamination, diagnostic symptoms, and other facts are presented. Areas of needed research are identified.

141. NORTON, S. A., J. J. AKIELASZEK, T. A. HAINES, K. L. STROMBORG, AND J. R. LONGCORE. 1982. Bedrock geologic control of sensitivity of aquatic ecosystems in the United States to acid deposition. National Atmospheric Deposition Program, Department of Geological Science, University of Maine, Orono. 11 pp.

Sensitivity maps are useful predictors of regions in New England with surface waters vulnerable to acidic precipitation. Alkalinity is satisfactorily predicted by bedrock type. Specific lake systems must be evaluated on an individual basis by using smaller scale geologic maps.

142. OLSON, J. E. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats – arctic tundra and alpine meadows. U.S. Fish Wildl. Serv., FWS/OBS-80/40.8. 29 pp.

This report describes the artic tundra and alpine meadow ecosystem features that determine sensitivity to air pollution. Data related to the effects of air pollutants on biota and whole ecosystems are reviewed. This report includes relevant information based on studies in other ecosystems. Suggestions are made for areas of further research.

143. PAUWELS, S. J., AND T. A. HAINES. 1986. Fish species distribution in relation to water chemistry in selected Maine lakes. Water Air Soil Pollut. 30:477–488.

Twenty-two lakes in Maine, ranging in pH from 4.4 to 7.0, were examined. No fish were caught in lakes with pH < 5.0. In lakes with pH below 6.0, brook trout (*Salvelinus fontinalis*), golden shiners (*Notemigonus crysoleucas*), and white suckers (*Catostomus commersoni*) were caught, but no common shiners (*Notropis cornutus*) or creek chubs (*Semotilus atromaculatus*). Fishless lakes differed from other lakes in water chemistry variables related to acidity. Among lakes containing fish, factors related to the number of species collected were lake surface area and maximum diversity.

144. PETERSON, M. A. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats – critical habitats of threatened and endangered species. U.S. Fish Wildl. Serv., FWS/OBS-80/40.11. 55 pp.

This report describes general aspects of relevant legislation protecting threatened and endangered species and their habitats. Major stresses to these species and their habitats are identified. Potential

effects of air pollution and acid rain on food resources, physiology, and breeding habitat, as well as on ecosystem structure and function, are outlined.

145. PETERSON, M. A. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats—grasslands. U.S. Fish Wildl. Serv., FWS/OBS-80/40.7. 63 pp.

This report describes general aspects of grassland ecosystems relevant to a discussion of air pollution effects; describes plant, animal, and ecosystem responses to air pollution; and discusses future research.

146. PETERSON, M. A. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats—introduction. U.S. Fish Wildl. Serv., FWS/OBS-80/40.3. 181 pp.

This introductory volume synthesizes the results of scientific research related to air pollution effects on fish and wildlife resources. A general summary of pollutant origins, atmospheric transport, transformation, and deposition is presented. In addition, the report describes plant, animal, and ecosystem responses to air pollution as well as factors affecting the sensitivity of receptive ecosystems.

147. PETERSON, M. A. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats—urban ecosystems. U.S. Fish Wildl. Serv., FWS/OBS-80/40.10. 89 pp.

General aspects of urban ecosystems relevant to a discussion of air pollution effects are presented along with an outline of various other types of ecosystem stresses. The potential use of biological indicators in monitoring ambient urban air pollution is introduced.

148. POTTER, W. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats—lakes. U.S. Fish Wildl. Serv., FWS/OBS-80/40.4. 121 pp.

This report summarizes the results of scientific research related to air pollution effects on fish and wildlife associated with lakes and wetlands. The characteristics that indicate lake sensitivity to air pollutants are presented. Socioeconomic aspects of air pollution effects on lake ecosystems are discussed.

149. POTTER, W., AND B. K. CHANG. 1982. The effects of air pollution and acid rain on fish, wildlife, and their habitats—rivers and streams. U.S. Fish Wildl. Serv., FWS/OBS-80/40.5. 52 pp.

This report synthesizes research results of effects of air pollutants on rivers and streams. The characteristics that reflect river and stream sensitivity to air pollutants are presented.

150. POWELL, D. E. 1986. Effects of pH on the release of aluminum, cadmium, and lead from littoral and profundal sediments of lakes Clara and McGrath, northern Wisconsin. M.S. thesis, University of Wisconsin, LaCrosse. 125 pp.

The effects of acidification on release of Al, Cd, and Pb from sediments into pore waters was studied in profundal and littoral sediments of two northern Wisconsin lakes. Except for Cd in littoral sediments, pore water concentrations of all three metals and color decreased as sediment pH decreased to around 4.5. The decrease in Al, Cd, and Pb concentrations in sediment pore water seemed to depend on the amount of dissolved organic material, primarily humic and fulvic acids, present. Dissolved organic materials complexed 98% of the dissolved Al and Pb and 63–86% of the dissolved Cd in the profundal natural sediments. In contrast, dissolved organic materials complexed 23–65% and 20–81% of the dissolved Al and Pb in the natural littoral sediments.

151. RADA, R. G., J. G. WIENER, M. R. WINFREY, AND D. E. POWELL. 1989. Recent increases in atmospheric deposition of mercury to north-central Wisconsin lakes inferred from sediment analyses. Arch. Environ. Contam. Toxicol. 18:175–181.

Profiles of total mercury concentrations in sediments were examined in 11 lakes in north-central Wisconsin having a broad range of pH and alkalinity. Mercury concentrations were greatest in the top 15 cm of the cores and much lower in the deeper strata. The increase in the mercury content of recent sediments was attributed to increased atmospheric deposition. Most of the lakes were low-alkalinity, receiving most of their hydrologic input from precipitation. The data imply that a potentially significant fraction of high mercury burdens in game fish originated from atmospheric sources.

152. RAGO, P. J., AND R. M. DORAZIO. 1984. Statistical inference in life-table experiments; the finite rate of increase. Can. J. Fish. Aquat. Sci. 41:1361–1374.

Life-table experiments are often used to examine the effects of food level, toxicants, and other experimental treatments on a population's finite rate of increase (λ). Though methods for computing the variance of λ have been suggested, the sampling distribution of λ, needed for statistical inference, has not been described. Monte Carlo procedures were used to simulate sampling distributions of λ for various assumptions regarding survivorship, fecundity schedules, and initial cohort sizes. The procedure was illustrated with life-table data from *Daphnia pulex* cohorts raised at different pH levels. A Taylor series variance estimator yields confidence intervals for λ that approximate those obtained from simulations.

153. RAGO, P. J., AND R. K. SCHREIBER, EDITORS. 1985. Acid rain and fisheries: a debate of issues. Symposium proceedings of the 114th annual meeting of the American Fisheries Society, Cornell University, Ithaca, N.Y., 12–16 August 1984. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.21). 106 pp.

A symposium was held to focus discussion on the more controversial aspects of acidic deposition and its effects on fish. This volume includes six of the papers presented and two extended abstracts. Topics covered the complexity of decision-making at the national level, the role of science in the legislative process, how natural processes and land use practices must be considered as factors responsible for decreased pH, how estimating fish losses cannot be based on pH alone, experimental evidence that low pH and aluminum increase hatching of brook trout (*Salvelinus fontinalis*), and a summary of field and laboratory evidence of acidic deposition effects on fishery resources of Ontario.

154. RAGO, P. J., AND J. G. WIENER. 1986. Does pH affect fish species richness when lake area is considered? Trans. Am. Fish. Soc. 115:438–447.

Species richness of fish communities was found to be correlated with lake pH and lake size. Two statistical methods were used, analysis of covariance and a nonparametric blocked comparison test, to remove the effects of lake area on comparing species richness in low-pH and high-pH lakes. Data on water chemistry and fish communities from surveys of lakes in Ontario and northern Wisconsin were used. Lakes with pH 6.0 or less had significantly fewer fish species than lakes with pH 6.0 or greater when the effect of lake area was considered. It was recommended that the blocked comparison test be used for separating the effects of lake area and pH on species richness.

155. RAHEL, F. J. 1985. Biogeographic influences, species interactions and lake acidification. Pages 30–41 *in* P. J. Rago and R. K. Schreiber, eds. Acid rain and fisheries: a debate of issues. Symposium proceedings of the 114th annual meeting of the American Fisheries Society, Cornell University, Ithaca, N.Y., 12–16 August 1984. U.S. Fish Wildl. Serv., Biol. Rep. 80(40.21). 106 pp.

Biogeographic analysis was used to identify abiotic factors which influence fish species distributions. The author examined the roles of lake size, isolation, and alkalinity in structuring fish communities in northern Wisconsin lakes. Northern Wisconsin lakes with high alkalinity had more fish species than low-alkalinity lakes of similar size. Lake isolation seemed to have little effect on fish community composition. Examining species composition in lakes partitioned on the basis of size, alkalinity, and isolation helps to clarify reasons for the absence of many fish species from small, low-alkalinity seepage lakes in northern Wisconsin.

156. RATTNER, B. A., G. M. HARAMIS, D. S. CHU, C. M. BUNCK, AND C. G. SCANES. 1987. Growth and physiological condition of black ducks reared on acidified wetlands. Can. J. Zool. 65:2953–2958.

Recruitment, growth, and physiological condition were monitored in ducklings foraging for a 10-day trial on both acidified and circumneutral fish-free emergent wetlands. Ducklings on acidified wetlands grew poorly compared to ducklings on circumneutral wetlands. Ducklings showing poor growth had lower hematocrit, plasma protein, glucose, and cholesterol concentrations. These findings suggest that acid deposition may lower food production in wetlands and ultimately impair duckling growth, condition, and survival.

157. RATTNER, B. A., G. M. HARAMIS, G. LINDER, AND D. S. CHU. 1985. Growth and blood chemistry of ducklings reared on acidified wetlands. Am. Zool. 25(4):17A.

Growth and physiological condition were monitored in captive-reared American black ducks (*Anas rubripes*) exposed for 10-day trials to control (pH 6.8) and acidified (pH 5.0) manmade emergent wetlands. Impaired growth (body weight, culmen, and tarsus length) and increased mortality (50%) were apparent in broods reared on acidified wetlands. Ducklings exhibiting poor

growth had reduced hematocrit, plasma protein, and cholesterol levels. These birds also had elevated plasma uric acid concentration and creatine kinase activity, and elevated plasma K+ levels. Based on overt appearance, growth, and blood chemistry, ducklings exposed to acidified wetlands were in poorer condition than those exposed to circumneutral wetlands.

158. RICE, D. A., T. K. TSAY, S. E. EFFLER, AND C. T. DRISCOLL. 1989. Modeling thermal stratification in a transparent Adirondack lake. J. Water Resour. Plan. Manage. In press.

A mixed-layer thermal stratification model was calibrated for Woods Lake for most of the open water period of 1985. The model also performed well in simulating the stratification regime of the lake the following year. The model may aid assessments of the effects of acidification on the thermal characteristics of lakes. It may also be a valuable management tool for evaluating the potential of remedial programs for reestablishing stratification.

159. ROELLE, J. E., A. K. ANDREWS, G. T. AUBLE, D. B. HAMILTON, R. L. JOHNSON, AND J. F. SISLER. 1984. A framework for assessing the impacts of acidic deposition on forest and aquatic resources: results of a workshop for the National Acid Precipitation Assessment Program. U.S. Fish Wildl. Serv., FWS/OBS-84/16. 80 pp.

This report is a synthesis of the discussions and conclusions of a workshop designed to outline a framework for assessing the effects of acidic deposition on forests and aquatic resources. Workshop activities focused on three principal topics: definitions of current damage and implications for assessment methodologies, conceptual models of damages, and procedures for economic evaluation of damages to the resource.

160. RUGGABER, G. J. 1988. Development and application of a thermal stratification model to Adirondack lakes. M.S. thesis, Syracuse University, Syracuse, N.Y. 136 pp.

Results of this study suggest that accurate depiction of thermal characteristics in shallow, transparent lakes requires consideration of the sediment heat budget. The UFILS1 model was applied on a regional scale to establish the transparency and maximum depth requirements for stratification. The regional analysis indicates that the percentage of lakes in each stratification category is highly dependent on the light attenuation coefficient. It may also serve as a useful management tool for water quality applications.

161. RUGGABER, G. J., T. K. TSAY, S. W. EFFLER, AND C. T. DRISCOLL. 1989. Thermal stratification of lakes with sediment heat flux. Hydraulics Division, American Society of Chemical Engineers. In press.

Application of traditional thermal stratification models to shallow transparent lakes often results in simulations characterized by hypolimnetic overheating and premature turnover. To accommodate this phenomenon, a sediment heat flux component was developed and incorporated into a one-dimensional, mixed-layer thermal stratification model, UFILS1. The modified model was applied to four physically representative lakes in the Adirondacks from 1984 to 1986. Recalibration and verification of UFILS1, including the sediment term, significantly improved model predictions for shallow lakes, while yielding little change in the model performance for deeper lakes. These results suggest that the accurate depiction of thermal characteristics in shallow, transparent lakes requires consideration of the sediment heat flux.

162. SCHMIDT, P. S. 1985. Major ion and metal (Al, Cd, and Pb) chemistry of softwater lakes in northern Wisconsin. M.S. thesis, University of Wisconsin, LaCrosse. 136 pp.

The major ion and metal (Al, Cd, Pb) chemistry of 14 softwater lakes was studied. The major anion was sulfate in the low-pH (<6.5) lakes and bicarbonate in the circumneutral lakes. Calcium concentrations were significantly lower in the low-pH lakes (annual mean 1.12–1.98 mg/L) than in the circumneutral lakes (annual mean 4.30–10.10 mg/L). Four acidification models were applied to the data to assess lake acidity. Mean waterborne concentrations of total Al, Cd, and Pb ranged from 7–172 μg/L, 9–211 ng/L, and 0.08–1.40 μg/L, respectively, and were inversely correlated with pH. Al, Cd, and Pb concentrations were higher in the low-pH lakes, but the relative magnitude of the difference was less pronounced for Pb. Concentrations of these metals were also correlated with alkalinity, sulfate concentration, and relative visibility.

163. SCHOFIELD, C. L., S. P. GLOSS, AND D. JOSEPHSON. 1986. Extensive evaluation of lake liming, restocking strategies, and fish population

response in acidic lakes following neutralization by liming. Interim progress report, U.S. Fish Wildl. Serv., NEC-86/18. 117 pp.

Ten small, acidic lakes in the Adirondack mountains were selected for neutralization experiments to evaluate the response of stocked brook trout populations to liming and reacidification. Annual survival of stocked trout was relatively high (40–80%) in those lakes that maintained circumneutral water quality during the first year after liming. Low survival (0–20%) was observed during reacidification, and annual survival rates were significantly correlated with mean epilimnetic pH during spring turnover.

164. SCHRECK, C. B., AND H. W. LI. 1984. Impact of surface water acidification on commercially and recreationally important salmonid fishes: effects on reproductive success and recruitment. Completion report, Oregon Cooperative Fishery Research Unit, Oregon State University, Corvallis, Interagency Agreement No. AD-14F21A100. 70 pp.

The effects of low environmental pH on salmonid reproduction were evaluated using rainbow trout as a model. Gametogenic performance and subsequent survival and fitness of early life stages of salmonids may be influenced by environmental acidity. Results indicate that acid-stressed fish are more sensitive to additional stresses even though they may appear to be physiologically normal.

165. SCHREIBER, R. K. 1980. Acid rain: industrial fallout in the north woods. U.S. Fish Wildl. Serv., Fish Wildl. News August–September:8–9.

The author describes the problem of acid rain and the research the U.S. Fish and Wildlife Service is conducting to better understand the effects of air pollution and acid rain on fish and wildlife resources. This research focuses on the possible effects on aquatic and terrestrial ecosystems from burning coal for electric power generation. The Service also supports research and technology development to minimize the negative effects of acid rain on fish and wildlife.

166. SCHREIBER, R. K. 1985. Acid precipitation mitigation: implementation of the U.S. Fish and Wildlife Service program. Page 298 *in* H. C. Martin, ed. Proceedings of the international symposium on acidic precipitation, Muskoka, Ontario, Canada, 15–20 September 1985.

A brief description of the Federal Acid Precipitation Mitigation Program is presented. This program is designed to evaluate mitigation strategies for reestablishing healthy biological communities. A discussion of site selection criteria and biological and chemical protocols is presented.

167. SCHREIBER, R. K. 1985. The Acid Precipitation Mitigation Program (APMP). Pages 4–10 *in* J. C. White, ed. Liming acidic waters: environmental and policy concerns. Symposium proceedings, Albany, N.Y., October 1985.

This paper is a brief overview of the Federal research program on acid precipitation and the current research effort addressing mitigation.

168. SCHREIBER, R. K. 1989. Cooperative Federal–State liming research on surface waters impacted by acidity. Water Air Soil Pollut. 41:53–73.

The ecological changes accompanying limestone mitigation of streams and lakes are being investigated in a cooperative program between the U.S. Fish and Wildlife Service and individual States. Streams in Massachusetts, Tennessee, and West Virginia, and a lake in Minnesota are included in this 5-year research program. Physical, chemical, and biological variables are monitored before and after treatment. Management guidelines will be generated from program results.

169. SCHREIBER, R. K., REVIEWER. 1989. REGENS, J. L., AND R. W. RYCROFT. 1988. The acid rain controversy. University of Pittsburgh Press, Pittsburgh, Pa. 228 pp. Wildl. Rev. 213:314.

This book chronicles the acid rain controversy, from air quality and air management to environmental politics. Its six chapters focus on the emergence of the problem and questions dealing with scientific uncertainty, existing control technologies and mitigation strategies, estimation of economic costs and benefits, the political environment, and the prospects for policy making. This book provides a good basic introduction to the economic and political aspects of the acid rain debate.

170. SCHREIBER, R. K., AND D. L. BRITT. 1987. Acid precipitation mitigation: implementation of the U.S. Fish and Wildlife Service research program. Fisheries 12(3):2–6.

The U.S. Fish and Wildlife Service has initiated a research program to analyze and evaluate ecological responses to mitigation strategies for

surface waters. A 5-year research program was implemented for representative stream and lake sites in cooperation with States in the Northeast, Southeast, and upper Midwest. The program determines the physical, chemical, and biological characteristics of the aquatic system before treatment and monitors key variables for a period after treatment. These studies are part of the National Acid Precipitation Assessment Program. The results will provide guidance for resource managers electing to implement mitigation activities.

171. SCHREIBER, R. K., AND J. BROGAN. 1981. Coal combustion: concern for fish and wildlife resources. Pages 19-24 *in* M. H. Tress and J. C. Dawson, eds. Proceedings of the Governors' conference on expanding the use of coal in New York State: problems and issues, Albany, 21 May 1981.

Concomitant with the new emphasis on coal combustion is a concern for the environmental costs associated with the airborne emissions and emission-abatement wastes. Adverse ecological effects may result during coal handling, processing, combustion, release of emissions, and waste disposal. The U.S. Fish and Wildlife Service has developed a number of technical documents that provide guidance to the biologists that analyze and evaluate effects of coal-fired generating facilities. This paper is an overview of the types of information in these documents.

172. SCHREIBER, R. K., C. D. GOODYEAR, AND W. A. HARTMAN. 1988. Challenges and progress in the Federal–State liming research program. Lake Line 8(3). 5 pp.

A review paper on the Federal Acid Precipitation Mitigation Program and changes in protocols that occurred during the first year of pretreatment data collection. The liming techniques used in this program are discussed.

173. SCHREIBER, R. K., AND W. A. HARTMAN. 1987. Lake and stream mitigation research: progress in the Federal–State program. Pages 1–13 *in* Proceedings of the 80th annual meeting of the Air Pollution Control Association, New York, 21–26 June 1987. Paper No. 87-35.1.

This paper describes the study sites in the Federal–State mitigation research program and presents some of the preliminary results from the first year of field and laboratory work. In situ bioassays show that the water quality of the study streams in Massachusetts and West Virginia will not support trout populations. Treatment strategies were scheduled to be implemented in fall 1987 and spring 1988.

174. SCHREIBER, R. K., AND J. R. NEWMAN. 1987. Air quality in wildernesses: a state-of-knowledge review. Pages 104–134 *in* R. C. Lucas, compiler. Proceedings of the national wilderness resources conference: issues, state-of-knowledge, future directions. Fort Collins, Colo., 23–26 July 1985. U.S. For. Serv., Gen. Tech. Rep. INT-220.

This paper provides an overview of air quality legislation pertaining to wilderness, a brief summary of air quality conditions potentially affecting wildernesses, and a discussion of research efforts addressing air quality and its influence on aquatic and terrestrial ecosystems. A limited survey of Federal land managers responsible for wilderness areas gives insight into the current ecological understanding, research, and information needs required to protect and maintain these areas.

175. SCHREIBER, R. K., AND J. R. NEWMAN. 1988. Acid precipitation effects on forest habitat: implications for wildlife. Conserv. Biol. 2:249–259.

This paper provides an overview of current information on the effects of acidic deposition on animal resources in forests. The effects of acid precipitation on forest resources and the potential for subsequent change in forest structure and function imply that an effect on wildlife inhabitants is also occurring.

176. SCHREIBER, R. K., AND J. R. NEWMAN. 1989. The nature and effects of atmospheric deposition on wilderness: monitoring and research needs. Pages 154–159 *in* Proceedings of the Society of American Foresters, Rochester, N.Y., 16–19 October 1988. Soc. Am. For. Publ. 88–01.

The air transports a variety of pollutants. Deposition of these pollutants in remote areas, such as in wilderness, raises a new concern for resource managers. This paper reviews the ecological effects of air pollutants and discusses various air monitoring strategies for wilderness areas.

177. SCHREIBER, R. K., AND P. J. RAGO. 1984. The Federal plan for mitigation of acid precipitation effects in the United States: opportunities for basic and applied research. Fisheries 9(1): 31–36.

This paper describes the development of mitigation measures for aquatic ecosystems as an objective of the National Acid Precipitation Assessment Program. Development of mitigation

is viewed as not only a response to a pressing national need, but as a unique opportunity for basic and applied research. An active research program on mitigation methods can provide insight into the structure of aquatic systems undergoing acidification.

178. SCHREIBER, R. K., AND R. F. VILLELLA. 1985. Influence of airborne pollutants on forest wildlife. Pages 267–284 *in* G. Heuer, compiler. Air pollutants effects on forest ecosystems. Acid Rain Foundation, St. Paul, Minn.

This paper reviews current research and points out that little information is available on wildlife resources in forest ecosystems subjected to air pollutants. Conflicting information on effects on waterfowl is presented, while amphibian studies indicate life stage and species-specific responses to low-pH waters.

179. SINGER, R., G. L. EVANS, AND N. C. PRATT. 1984. Phytoplankton limitation by phosphorus and zooplankton grazing in an acidic Adirondack lake. J. Freshwater Ecol. 2:423–434.

Small (20-L) enclosures were used to study the effects of phosphorus addition and zooplankton removal on the phytoplankton of an acidic lake in the Adirondack mountains. In spite of inorganic mechanisms that are capable of sequestering phosphate under acidic conditions, the phytoplankton population bloomed after the addition of $80\,\mu g \cdot L^{-1}$ of phosphate. The response was measured by cell counts of the dominant phytoplankter, *Chlamydomonas*, and changes in chlorophyll *a* concentration. About half the number of algal cells were present after the 2-week incubation when zooplankton were not removed, indicating that zooplankton herbivory can influence, but not totally control, the algal production.

180. SKINNER, W. D., AND D. E. ARNOLD. 1989. Short-term biotic response before and during the treatment of an acid mine drainage with sodium carbonate. Hydrobiologia. In press.

When a mine drainage stream with a historical record of biological data was treated with sodium carbonate for 7 days, total number of invertebrates and number of taxa colonizing bricks during three pretreatment periods (8, 10, and 18 days) did not differ from the single treatment period (7 days). However, two species of *Baetis* (mayflies) did increase in the treatment section during treatment. The number of brook trout (*Salvelinus fontinalis*) in the treatment section also increased. The results indicate that motile species are able to respond within 7 days to treatment of acidity in streams, but longer treatment may be required to produce communitywide responses.

181. STROMBORG, K. L., AND J. R. LONGCORE. 1984. Distribution and effects of acidic deposition on wildlife and ecosystems. Pages 221–232 *in* P. Kacmar and J. Legath, eds. Toxic effects of chemical environmental contaminants on production and reproduction ability in free-living animals. Symposium proceedings, High Tatras, Patria Hotel, Strbski Pleso, Czechoslovakia, 3–4 October 1983.

Brief paper on how acid rain may alter the vegetative structure or primary productivity of wetlands, which may indirectly affect avian populations by causing decreased invertebrate productivity and consequent food resource limitations.

182. STROMBORG, K. L., AND J. R. LONGCORE. 1987. Distribution and effects of acidic deposition on wildlife ecosystems. Pages 221–232 *in* Peter Kacmar and J. Legath, eds. Collected reports from the Czechloslovak–American symposium on toxic effects of chemical environmental contaminants on production and reproduction ability in free-living animals, University of Veterinary Medicine, Kosice, Czechoslovakia, 3–4 October 1983.

(abstract same as Stromborg and Longcore 1984)

183. TRIAL, J. G., AND J. G. STANLEY. 1984. Calibrating effects of acidity on Atlantic salmon for use in habitat suitability models. Completion report 14-34-0001-0121, Land and Water Resources Center, University of Maine, Orono. 37 pp.

In a laboratory study, pH of 5.0–6.0 had no effect on the temperature or oxygen selected by parr. At pH 4.0 parr fatigued when swimming at 30 cm/s, whereas at pH 4.5 they fatigued at about 50 cm/s; 50 ppm $CaCl_2$ prevented fatigue. Habitat suitability indexes that included a model for effects of pH predicted habitat values 70% lower than when the pH model was not included.

184. TURNER, L. J., AND D. K. FOWLER. 1981. Utilization of surface mine ponds in east Tennessee by breeding amphibians. U.S. Fish Wildl. Serv., FWS/OBS-81/08. 22 pp.

Breeding amphibians were found in 21 of 24 ponds on the Ollis Creek surface mine in east Tennessee.

Twelve species were identified in ponds that ranged from pH 4.0 to 8.0. Although ponds with low pH were used by breeding amphibians, significantly more amphibian species were found in ponds with higher pH. Findings indicated high biological productivity in the surface mine ponds examined. Aquatic vegetation and insects were present, and a diverse wildlife fauna used the study ponds. Surface mine ponds were found to supply an important habitat component for a variety of wildlife species.

185. TURNER, L. D., J. F. MCFADDEN, AND E. L. MORGAN. 1988. Using satellite data communications and automated biomonitoring to assess the effects of acid precipitation on rainbow trout (*Salmo gairdneri*) breathing rates. J. Tenn. Acad. Sci. 63(2):57.

Two data collection platforms equipped with portable computers were used to record breathing rates of rainbow trout (*Oncorhychus mykiss*, formerly *Salmo gairdneri*) while pH, temperature, dissolved oxygen, conductivity, and flow were recorded. Data were transmitted via earth satellite every 3 h and received at a local readout ground station. Interpretation of data shows a trout diurnal response curve. Preliminary results show a complex relations between the pH hydrograph and breathing rate.

186. U.S. FISH AND WILDLIFE SERVICE, EASTERN ENERGY AND LAND USE TEAM. 1982. Effects of acid precipitation on aquatic resources: results of modeling workshop. FWS/OBS-80/40.12. 129 pp.

The report identifies priority research needed for a better understanding of the acidification process and its effects on aquatic resources of watershed ecosystems. A preliminary computer simulation model is presented.

187. U.S. FISH AND WILDLIFE SERVICE, EASTERN ENERGY AND LAND USE TEAM. 1982. Liming of acidified waters: issues and research – a report of the International Liming Workshop. FWS/OBS-80/40.14. 36 pp.

Summary of workshop held to identify critical uncertainties associated with liming of surface waters and to develop a research strategy for the design of field and laboratory experiments to resolve these uncertainties.

188. VILLELLA, R. F., AND R. K. SCHREIBER. 1986. The Federal Acid Precipitation Mitigation Program. Lake Line 6:30–31.

The article briefly describes the U.S. Fish and Wildlife Service's Acid Precipitation Mitigation Program. This program is designed to evaluate the ecological responses to mitigative liming in lakes and streams affected by acid deposition and those potentially acidified. The northeast, southeast, and north-central States have been identified as the three major regions for current mitigation research.

189. WEAVER, T. P. 1986. Overview of the Laurel Branch liming effects study. Page 45 *in* H. Olem, ed. Proceedings of the third annual acid rain conference for the southern Appalachians, Gatlinburg, Tenn., 27 October 1986.

The State of Tennessee entered into an agreement with the U.S. Fish and Wildlife Service to conduct a liming effects research program on Laurel Branch, a stream in east Tennessee. Two years of baseline biotic and abiotic sampling were scheduled, with the stream being limed in the third year of the 5-year project. One year of data collection had been completed. Remote real-time biological and physical data (pH, conductivity, and flow) were being collected with a Synergetics data collection platform via the NOAA GOES satellite system. Rainbow trout (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*) are being used as the test species to evaluate stress during acidic events.

190. WEAVER, T. P., E. MORGAN, J. B. MOORE, and H. OLEM. 1985. Acid mitigation study on Laurel Branch. Page 47 *in* H. Olem, ed. Proceedings: second annual acid rain conference for the southern Appalachians, Gatlinburg, Tenn., 28–30 October 1985.

The abstract briefly describes a proposed mitigation study on Laurel Branch, a stream in east Tennessee. The objective is to evaluate the effects of mitigative action on aquatic resources. The study is proposed as a 5-year cooperative study with the U.S. Fish and Wildlife Service and the State of Tennessee.

191. WEINER, G. S., C. B. SCHRECK, AND H. W. LI. 1986. Effects of low pH on reproduction of rainbow trout. Trans. Am. Fish. Soc. 115:75–82.

Rainbow trout (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*) reproduction in acidic water was studied. Adults were exposed to pH 4.5, 5.0, or 5.5 during the final 6 weeks of reproductive maturation. Progeny of acid-exposed females and control males had reduced survival through 7 days development, hatching, and yolk-sac absorption, showing that oogenesis is sensitive to acidic

conditions. Similar reductions in progeny survival of acid-exposed males and control females indicate the sensitivity of spermatogenesis to low ambient pH. For progeny of unexposed adults, survival through 7 days development and hatching was lower when reared at pH 4.5, 5.0, or 5.5 than at pH 6.5–7.1. No eggs exposed to pH 4.5 survived to the eyed stage. Reproduction of rainbow trout may be affected by environmental acidification to pH values below 5.5.

192. WIENER, J. G. 1983. Acidic precipitation: a selected, annotated listing of information sources. Fisheries 8(4): 7–11.

An annotated listing of recent documents concerning acid precipitation, including reviews, bibliographies, symposium proceedings, directories of scientists studying acid deposition, and research programs that were ongoing in 1983.

193. WIENER, J. G. 1983. Comparative analyses of fish populations in naturally acidic and circumneutral lakes in northern Wisconsin. U.S. Fish Wildl. Serv., FWS/OBS-80/40.16. 107 pp.

Fish communities in the low-pH lakes contained fewer species. Minnows and darters were well represented in circumneutral lakes, but absent or scarce in acidic lakes. Growth, condition, and serum calcium concentrations of bluegill (*Lepomis macrochirus*) were negatively correlated with population density. Results of serum calcium analyses suggested white suckers (*Catostomus commersoni*) were stressed in lakes with a fall pH equal to or less than 5.6 and waterborne calcium equal to or less than 2.0 mg/L. Concentrations of mercury, cadmium, and lead were significantly greater in fish in low-pH lakes than in fish in circumneutral lakes.

194. WIENER, J. G., CHAIRMAN. 1984. Proceedings of a symposium on mitigation techniques for acidified surface waters. Fisheries 9(1):2–42.

Papers presented at the 113th annual (1983) meeting of the American Fisheries Society. This session was directed specifically at acidification resulting from acidic deposition. Together, the authors provide a thorough review of recent advances in design and operation of neutralizing systems, ecological effects, and effective responses of fish populations and fisheries production.

195. WIENER, J. G. 1987. Metal contamination of fish in low pH lakes and potential implications for piscivorous wildlife. Trans. N. Am. Wildl. Nat. Resour. Conf. 52:645–657.

A review of findings concerning the chemistry and biological availability of three highly toxic and nonessential metals (Hg, Cd, Pb) in relation to lake chemistry and acidification was based on more than 80 recent references. Covered are factors influencing metal accumulation by fish in low-pH water and the threat posed to animals feeding on them.

196. WIENER, J. G. 1988. Effect of experimental acidification to pH 5.6 on mercury accumulation by yellow perch in Little Rock Lake, Wisconsin. Report of 1987 findings to the U.S. Environmental Protection Agency. 30 pp.

Results suggest that acidification enhances mercury accumulation by fish. The mean mercury concentration in whole yellow perch (*Perca flavescens*) from the acidified (pH 5.6) treatment basin was 12% greater than the concentration in yellow perch from the nonacidified (pH 6.1) reference basin in 1986. Statistical comparison of study results between treatment and reference basins within a given year seems the most useful approach to evaluate the effect of acidification on mercury accumulation by fish.

197. WIENER, J. G., AND J. M. EILERS. 1987. Chemical and biological status of lakes and streams in the upper Midwest: assessment of acidic deposition effects. Lake Reservoir Manage. 3:365–378.

Many lakes in the Upper Peninsula of Michigan, northeastern Minnesota, and northern Wisconsin have low acid neutralizing capacity (ANC) and may be susceptible to change by acidic deposition. Streams in this three-State region have high ANC and appear to be insensitive to acidic deposition. Given the general lack of quantitative fishery data for acidic Michigan and Wisconsin lakes, general conclusions concerning effects or absence of effects of acidification on the region's fishery resources are not possible.

198. WIENER, J. G., AND W. R. HANNEMAN. 1982. Growth and condition of bluegills in Wisconsin lakes: effects of population density and lake pH. Trans. Am. Fish. Soc. 111:761–767.

Five acidic and six circumneutral lakes were sampled. Although mean condition factors and mean total lengths varied significantly among lakes, the differences were not related to lake pH. They were negatively correlated with relative density of bluegills (*Lepomis macrochirus*).

Because density has a dominating effect, growth rates and condition factors are not useful as indicators of chronic, pH-related stress in bluegills.

199. WIENER, J. G., R. A. JACOBSON, P. S. SCHMIDT, AND P. R. HEINE. 1985. Serum calcium concentrations in white sucker, *Catostomus commersoni* Lacepede, and bluegill, *Lepomis macrochirus* Rafinesque, in northern Wisconsin lakes: relation to pH and waterborne calcium. J. Fish. Biol. 27:699–709.

Mean serum calcium concentrations were greater in female white suckers (*Catostomus commersoni*) in circumneutral lakes than in two acidic lakes, while mean concentrations in fish from the acidic lakes did not differ. No relation was found between serum calcium concentrations in bluegills (*Lepomis macrochirus*) and lake pH or waterborne calcium. Evidence suggested that serum calcium levels in bluegills are affected by density-dependent factors. The authors hypothesized that serum calcium levels in female white suckers are depressed by exposure to pH 6.0 or less. The potential use of serum calcium concentrations measured before spawning as an indicator of acid stress in synchronous spawners merits further research.

200. WIENER, J. G., R. E. MARTINI, T. B. SHEFFY, AND G. E. GLASS. 1989. Factors influencing mercury concentrations in walleyes in northern Wisconsin lakes. Trans. Am. Fish. Soc. In press.

Walleyes (*Stizostedion vitreum vitreum*) in northern Wisconsin lakes having low pH values were found to have higher body levels of mercury. Both pH and alkalinity were examined as factors influencing mercury accumulation in these fish.

201. WIENER, J. G., AND P. J. RAGO. 1987. A test of fluctuating asymmetry in bluegills (*Lepomis macrochirus* Rafinesque) as a measure of pH-related stress. Environ. Pollut. 44:27–36.

Fluctuating asymmetry of bilateral anatomical characters was measured in bluegills (*Lepomis macrochirus*) as an indicator of stress. Numbers of pored lateral line scales, pectoral fin rays, and gill rakers on the outer arch were found to be either unrelated or marginally related to lake pH or to waterborne calcium concentration. Fluctuating asymmetry in adult fishes was judged to be insensitive as a potential measure of pH-related stress.

202. WIENER, J. G., P. J. RAGO, AND J. M. EILERS. 1984. Species composition of fish communities in northern Wisconsin lakes: relation to pH. Pages 133–146 *in* G. R. Hendrey, ed. Early biotic responses to advancing lake acidification. Butterworth Publishers, Woburn, Mass.

This paper compares species composition and richness of fish communities in two groups of clearwater lakes in Wisconsin: six lakes had low pH and six were circumneutral. Fish community differences are discussed in terms of pH-related effects.

203. WIENER, J. G., P. M. STOKES, AND R. SLOAN. 1985. Bioaccumulation. Pages 18–24 *in* S. O. Quinn and N. Bloomfield, eds. Workshop proceedings – acidic deposition, trace contaminants, and their indirect human health effects: research needs. U.S. Environ. Prot. Agency, EPA/600/9-86/002.

Mercury was identified as the contaminant of primary concern in regard to human consumption of fish from acid-sensitive waters. Total mercury concentrations in edible flesh of piscivorous fish inhabiting low-pH waters frequently exceed 0.5 or 1.0 μg/g wet weight. Elevated mercury levels have been noted in fish inhabiting acidic waters in Ontario, Scandinavia, Wisconsin, and the Adirondack mountain region of New York. Several mechanisms were proposed as explanations of the relation between surface water acidity and mercury bioaccumulation. Other metals exhibiting elevated concentrations in acidic waters are cadmium, lead, and aluminum.

204. WINGER, P. V., P. J. LASIER, M. HUDY, D. FOWLER, AND M. J. VAN DEN AVYLE. 1987. Sensitivity of high-elevation streams in the southern Blue Ridge Province to acidic deposition. Water Resour. Bull. 23:379–386.

This study confirms the predicted potential sensitivity, quantifies the level of total alkalinity, and describes the chemical characteristics of 30 headwater streams in the southern Blue Ridge Province. Sensitivity based on total alkalinity and the calcite saturation index indicates that the headwater streams in this area are vulnerable to acidification. A single sampling appeared adequate for evaluating sensitivity based on total alkalinity, but multiple sampling is required for detecting changes in pH and alkalinity over time.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biol. Rep. 80(40.28)	2.	3. Recipient's Accession No.

4. Title and Subtitle Acid Rain Publications by the U.S. Fish and Wildlife Service, 1979-1989	5. Report Date August 1989
	6.
7. Author(s) Rita F. Villella	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Acid Precipitation Section National Fishery Research Center--Leetown U.S. Fish and Wildlife Service Box 700 Kearneysville, WV 25430	10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address U.S. Fish and Wildlife Service National Fishery Research Center--Leetown Box 700 Kearneysville, WV 25430	13. Type of Report & Period Covered Final 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report is an annotated bibliography of acid rain and related air quality publications authored or co-authored by the U.S. Fish and Wildlife Service employees or that have been supported by Service funding. This bibliography covers 10 years of research from 1979 to 1989. Research projects have covered the effects of acidity on water chemistry, aquatic invertebrates, amphibians, fish, and waterfowl. Specific projects have addressed important fish species such as rainbow trout, brook trout, Atlantic salmon, and striped bass. In addition to lake and stream studies, wetland and some terrestrial habitat work has also been conducted. Also included in this report is research on the ecological effects of liming surface waters and surrounding watersheds. The Service publications on acid rain research appear in conference proceedings, journal articles, and in-house scientific publications. Entries in the bibliography are arranged alphabetically by author.

17. Document Analysis a. Descriptors

acidification, pH, amphibians, fish, waterfowl, invertebrates, water chemistry, liming, bibliography

b. Identifiers/Open-Ended Terms

acid rain, alkalinity, mitigation, wetlands, lakes, rivers, streams, wildlife, waterfowl, fish

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited	unclassified	31
	20. Security Class (This Page) unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

☆ U.S. Government Printing Office: 1989—673-208/00020

Previous reports on air pollution and acid rain.

FWS/OBS-80/40.1	Effects of Air Emmissions on Wildlife Resources.
FWS/OBS-80/40.2	Potential Impacts of Low pH on Fish and Fish Populations.
FWS/OBS-80/40.3	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Introduction.
FWS/OBS-80/40.4	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Lakes.
FWS/OBS-80/40.5	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Rivers and Streams.
FWS/OBS-80/40.6	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Forests.
FWS/OBS-80/40.7	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Grasslands.
FWS/OBS-80/40.8	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Tundra and Alpine Meadows.
FWS/OBS-80/40.9	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Deserts and Steppes.
FWS/OBS-80/40.10	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Urban Ecosystems.
FWS/OBS-80/40.11	The Effects of Air Pollution and Acid Rain on Fish, Wildlife,and Their Habitats: Critical Habitats of Threatened and Endangered Species.
FWS/OBS-80/40.12	Effects of Acid Precipitation on Aquatic Resources: Results of Modeling Workshops.
FWS/OBS-80/40.13	Liming of Acidified Waters: A Review of Methods and Effects on Aquatic Ecosystems.
FWS/OBS-80/40.14	The Liming of Acidified Waters: Issues and Research—A Report of the International Liming Workshop.
FWS/OBS-80/40.15	A Regional Survey of Chemistry of Headwater Lakes and Streams in New England: Vulnerability to Acidification.
FWS/OBS-80/40.16	Comparative Analyses of Fish Populations in Naturally Acidic and Circumneutral Lakes in Northern Wisconsin.
FWS/OBS-80/40.17	Rocky Mountain Acidification Study.
FWS/OBS-80/40.18	Effects of Acidic Precipitation on Atlantic Salmon Rivers in New England.
FWS/OBS-80/40.19	Vulnerability of Selected Lakes and Streams in the Middle Atlantic Region to Acidification: A Regional Survey.
FWS/OBS-80/40.20	Interactions Among Waterfowl, Fishes, Invertebrates, and Macrophytes in Four Maine Lakes of Different Acidity.
Biol. Rep. 80(40.21)	Acid Rain and Fisheries: Symposium Proceedings of the American Fishery Society 114th Annual Meeting.
Biol. Rep. 80(40.22)	The Effect of Acidic Precipitaton on Amphibian Breeding in Temporary Ponds in Pennsylvania.
Biol. Rep. 80(40.23)	Predicting and Evaluating the Effects of Acidic Precipitation on Water Chemistry and Endemic Fish Populations in the Northeastern United States.
Biol. Rep. 80(40.24)	APMP Guidance Manual—Vol. I: APMP Research Requirements.
Biol. Rep. 80(40.25)	APMP Guidance Manual—Vol. II: Liming Materials and Methods.
Biol. Rep. 80(40.26)	Acid Precipitation Studies in Colorado and Wyoming: Interim Report of Surveys of Montane Amphibians and Water Chemistry.
Biol. Rep. 80(40.27)	Liming and Fisheries Management Guidlines for Acidified Lakes in the Adirondak Region.

TAKE PRIDE

in America

U.S. DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.